

# NCHRP

## SYNTHESIS 311

NATIONAL  
COOPERATIVE  
HIGHWAY  
RESEARCH  
PROGRAM

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### Performance Measures of Operational Effectiveness for Highway Segments and Systems

*A Synthesis of Highway Practice*

TRANSPORTATION RESEARCH BOARD  
OF THE NATIONAL ACADEMIES

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**NCHRP SYNTHESIS 311**

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**Performance Measures of Operational Effectiveness  
for Highway Segments and Systems**

***A Synthesis of Highway Practice***

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## **FOREWORD**

*By Staff  
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Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research and much from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, “Synthesis of Information Related to Highway Problems,” searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

The synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

## **PREFACE**

This report of the Transportation Research Board will be of interest to local, regional, state, and federal officials, as well as to other transportation professionals who work with them in examining the use of performance measures for the monitoring and operational management of highway segments and systems. The current state of the practice includes a wide and varied approach to performance measures, with more than 70 performance measures being identified in this synthesis. Those identified as being used the most successfully were those related to conditions experienced by the traveler, such as travel time, speed, and delay. Based on the survey results, the dimensions of operational performance that were the most relevant were the quantity of travel and the quality of travel.

This synthesis contains overview information culled from survey responses from state transportation agencies and metropolitan planning organizations. This information was combined with that from recent literature findings and ongoing research to address current practices across the nation.

A panel of experts in the subject area guided the work of organizing and evaluating the collected data and reviewed the final synthesis report. A consultant was engaged to collect and synthesize the information and to write this report. Both the consultant and the members of the oversight panel are acknowledged on the title page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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Crawford F. Jencks, Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-5 Committee and the Synthesis staff.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

# PERFORMANCE MEASURES OF OPERATIONAL EFFECTIVENESS FOR HIGHWAY SEGMENTS AND SYSTEMS

## SUMMARY

This synthesis examined the use of performance measures for the monitoring and operational management of highway segments and systems. The current state of the practice includes a wide and varied approach to performance measures, with more than 70 performance measures identified in this synthesis. An assessment of the relative strengths and weaknesses of these measures was performed. The measures that were identified as being used the most successfully directly reported conditions experienced by the traveler, such as travel time, speed, and delay. Measures that are derived from these basic units, primarily indices, were found to be less relevant to the operational environment than to policy planners. Based on the results of the survey of state departments of transportation and metropolitan planning organizations, the dimensions of operational performance that were the most relevant were the quantity of travel and the quality of travel.

Through this synthesis of research and practice, several research needs were identified to enhance and expand the state of the practice. These needs include developing common definitions for emerging performance measures such as travel reliability and other indices, as well as data quality and reporting guidelines that consider estimated standard errors. Guidelines for forecasting and considering alternate policy and development scenarios, and measures that support evacuations from natural and man-made disasters are also needed.

## INTRODUCTION

### BACKGROUND

During the 20th century surface transportation programs were substantially focused on the development of basic infrastructure networks. The challenge for transportation in the 21st century is managing and operating these transportation resources to deliver needed services to customers under varying conditions in the face of growing travel demand and capacity limitations. Performance measurement is emerging as a critical tool to help meet this challenge. Performance measurement is being used at several levels, ranging from day-to-day operations to long-term capital planning that enhances system operations. Performance measurement can also be used at the project level to identify design features that improve operations and at the policy level to allow stakeholders to evaluate the benefits of highway improvements.

However, evaluating and improving system operations through performance measures can be challenging. Data collection and analysis demands can be overwhelming. Different measures are appropriate for different audiences; for example, the public, elected officials, system planners, and operations managers. Some engineering measures may be useful in improving operations, but may not be effective in communicating meaningful information to the public.

### PURPOSE

This synthesis summarizes the practices used by state departments of transportation (DOTs), metropolitan planning organizations (MPOs), and local governments concerning highway operational performance measures and associated data collection. Specifically, this synthesis reports on

- Uses of performance measures,
- The intended audiences for performance measures,
- Reporting techniques for performance measures,
- Data collection techniques in support of the performance measures,
- The relative strengths and weaknesses of commonly used performance measures, and
- Examples of successful practices for performance measures.

### METHODOLOGY

This synthesis was conducted in four parts. The first was a literature review of documented research. The second was

a review of the practices of state and national transportation agencies. Third, a comprehensive survey of state transportation agencies and MPOs was undertaken. The results of parts one through three were then compiled and documented, and gaps in existing research and practices were identified.

### ORGANIZATION

This synthesis report is organized to provide an introduction to operational performance measures for highway systems and segments. A summary of performance measures programs is provided that progresses from general concepts through a number of case studies. An annotated bibliography is also provided for readers who may be interested in learning more.

Chapter two outlines the principles of performance measures, describes why these measures are needed, and reviews the key steps in performance-based management. It also describes how to identify highway systems and segments and how to define performance measures for these segments.

Chapter three summarizes the major relevant research documents and on-going efforts.

Chapter four summarizes the current state of practice in the areas of operational performance measures for highway systems and segments based on the study survey. The practice is summarized according to four classifications:

1. Federal and state guidelines and rules—Relevant federal and state guidelines and rules related to performance measures for operational efficiency are summarized.
2. Federal and state practices—Relevant federal and state projects and programs are summarized.
3. Practice by other organizations—Relevant practices by other organizations such as MPOs, and county and city governments are summarized based on the results of a literature review. The summary of federal, state, and other agency practices is based on a survey of state transportation agencies and MPOs conducted during the fall of 2001.
4. Common themes in evaluation and application—A summary of the common themes in the research and practice are provided. A matrix is developed that summarizes the relevant performance measures, their application, and usefulness.

Chapter five synthesizes the performance measures reported in the literature and the current state of the practice and discusses the strengths and weaknesses of the measures using the principles of performance measures identified in chapter two.

Chapter six summarizes the findings from the literature, agency questionnaire, state of the research, state of the

practice, and the major conclusions from the synthesis. Based on the state of the research, state of the practice, and conclusions, an agenda for research programs to improve the state of the practice is suggested.

Appendix A provides a copy of the survey of state DOTs and MPOs conducted as part of this research. A list of acronyms and abbreviations is also included.

## BASIC CONCEPTS AND DEFINITIONS

Modern use of performance measures and performance measurement systems rose out of the Deming Total Quality Management movement of the 1950s in Japan. Although performance measures had been used in some applications before this, the science of performance measurement and statistics was derived from the principles espoused in his 14 points. These principles are intended to provide a structured system for satisfying internal and external customers and suppliers by integrating the business environment, continuous improvement, and breakthroughs with development, improvement, and maintenance cycles while changing organizational culture. These principles rely on developing goals that can be related to measurable results (such as reducing the number of manufactured parts that do not meet expectation), monitoring those results, and assessing strategies to improve performance.

Prior to the late 1980s, Total Quality Management and performance measures were primarily used in industrial applications and in the private sector. As government resources became limited during the recessions of the 1970s and 1980s, the public began to take a greater interest in making government accountable to primary agency missions and goals. Some government agencies adopted more private sector business practices that included performance monitoring and measurement principles in response to these pressures. However, there was little national consistency in these practices. In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) promoted the national use of performance measures and performance-based planning through the recommendation of congestion, safety, intermodal, public transit, pavement, and bridge management systems. Many state transportation agencies and MPOs adopted these management systems and related practices although they were made optional (Shaw 1996). In 1993, President Clinton signed the Government Performance and Results Act of 1993, further institutionalizing performance measures in the federal government and requiring that specific measures be established and tracked for most major federal programs. These recommendations were based on successful programs in several state DOTs and MPOs. These measures were derived from strategic planning activities that require agencies to report on how they achieve goals through performance measures. In 1997, the National Performance Review report, *Serving the American Public: Best Practices in Customer-Driven Strategic Planning*, recommended best practices for performance measurement for federal programs and local governments.

When addressing performance measures applications for the operational effectiveness of highway systems and segments, several common questions were identified that can be used to explain the basic concepts and definitions relevant to these applications.

- What are performance measures?
- Why have performance measurement?
- How do you define highway systems and segments?
- How do you define performance measures for the operational effectiveness of highway segments and systems?
- What are the key steps in performance-based management?

### WHAT ARE PERFORMANCE MEASURES?

NCHRP Project 8-32(02), “Multimodal Transportation: Performance-Based Planning Process” (1998), defines performance measurement as

the use of statistical evidence to determine progress toward specific defined organizational objectives. This includes both evidence of actual fact, such as measurement of pavement surface smoothness, and measurement of customer perception such as would be accomplished through a customer satisfaction survey. In a service industry such as transportation, the performance measurement process starts by defining precisely the services the organization promises to provide, including the quality or level of service (LOS) (e.g., timeliness, reliability, etc.) that is to be delivered. There are often good opportunities for collecting feedback from system users in “real time,” since the transportation service is often “consumed” at the same time it is “produced.” Performance measures provide information to managers about how well that bundle of services is being provided. Performance measures should reflect the satisfaction of the transportation service user in addition to those concerns of the system owner or operator.

An alternative and more succinct definition as reported by the FHWA from the National Performance Review is as follows:

Performance measurement is a process of assessing progress toward achieving predetermined goals, including information on the efficiency with which resources are transformed into goods and services (outputs), the quality of those outputs (how well they are delivered to clients and the extent to which clients are satisfied) and outcomes (the results of a program activity compared to its intended purpose), and the effectiveness of government operations in terms of their specific contributions to program objectives.

## WHY HAVE PERFORMANCE MEASUREMENT?

Performance measures can have profound effects on the effectiveness of transportation systems and services. For example, prior to the mid-1980s, airlines in the United States commonly reported on the success of their “on-time departures.” Because the perception of success, with both the American public and the airlines, was derived from this measure, individual aircraft crews had to maintain on-time departure schedules that resulted in significant inefficiencies. Flight arrivals were often delayed due to the priority given to take-offs and many aircraft spent unnecessary time airborne circulating destination airports, which resulted in excess fuel consumption and labor costs. When measures evolved to “on-time arrivals,” airlines began scheduling arrival times at their destination airports and delaying departures to minimize the time spent airborne. Airlines saved on fuel costs and air travel became more affordable and reliable. Following this paradigm shift in the airline industry, air travel increased dramatically and economic productivity and leisure travel expanded providing many positive economic benefits to the nation’s economy.

Performance measures can be used with highway systems and segments to monitor the effectiveness of operational strategies and to assess the success of achieving targets commonly called yardsticks or benchmarks. In an operational context these measures can be used in “near real-time” to assess the performance of the highway system and implement operational strategies to improve or maximize throughput or to minimize delay. Many agencies are now using performance measures to achieve operational efficiencies and to improve the reliability of highways similar to the gains that were made in the aviation industry in the 1980s.

Performance measures of operational effectiveness are used in the planning and systems engineering context to prioritize projects, provide feedback on the effectiveness of longer-term strategies, refine goals and objectives, and improve processes for the delivery of transportation services. Performance measures in planning are principally used in reporting trends, conditions, and outcomes resulting from transportation improvements. The Florida DOT’s *Florida’s Mobility Performance Measures Program* (2000) notes the following reasons for using performance measures:

Citizens, elected officials, policy makers, and transportation professionals are seeking new ways of measuring the performance of the transportation system to answer the following questions:

- How do we improve transportation to serve people and commerce in Florida?
- What are we getting from our investment in transportation?
- Are we investing in transportation as efficiently as possible?

Performance measures are needed to answer these questions and to track performance over time. They also provide accountability and link strategic planning to resource allocation. By defining specific measures, the Florida Department of Transportation is able to measure the effectiveness of programs in meeting Department objectives. Secretary of Transportation Tom Barry has stated “We measure ourselves for two reasons—to make sure we are spending the taxpayers’ money as efficiently as possible and to try to improve how we provide transportation to the people of Florida.” Performance measures are becoming an important part of the way government works in Florida, and the Department of Transportation is helping to lead the way in this process.

Pickrell and Neumann (2000) in the presentation “Linking Performance Measures With Decision Making” at the TRB 79th Annual Meeting summarized the following reasons for adopting performance measures:

- **Accountability**—Performance measurement provides a means of determining whether resources are being allocated to the priority needs that have been identified, through reporting on performance and results to external or higher-level entities.
- **Efficiency**—Performance measurement focuses actions and resources on organizational outputs and the process of delivery; in essence, in this context, performance measurement becomes an internal management process.
- **Effectiveness**—Related primarily to planning and goals achievement, performance measurement in this case provides a linkage between ultimate outcomes of policy decisions and the more immediate actions of transportation agencies.
- **Communications**—Performance measurement provides better information to customers and stakeholders on the progress being made toward desired goals and objectives, or deterioration of performance, in some cases.
- **Clarity**—By focusing on the desired ultimate outcomes of decisions, performance measures can lend clarity to the purpose of an agency’s actions and expenditures.
- **Improvement**—Performance measurement allows periodic refinement of programs and service delivery given more intermediate results of system monitoring.

## HOW DO YOU DEFINE HIGHWAY SYSTEMS AND SEGMENTS?

As part of undertaking this synthesis there was a need for defining highway segments and systems for use in the review and analysis of performance measures. The 2000 *Highway Capacity Manual* (HCM) defines a structure consisting of points, segments, and systems (Figure 1). This definition was adopted to limit the range and scope of performance measurement practice for synthesis.

## Generalized Highway System Structure

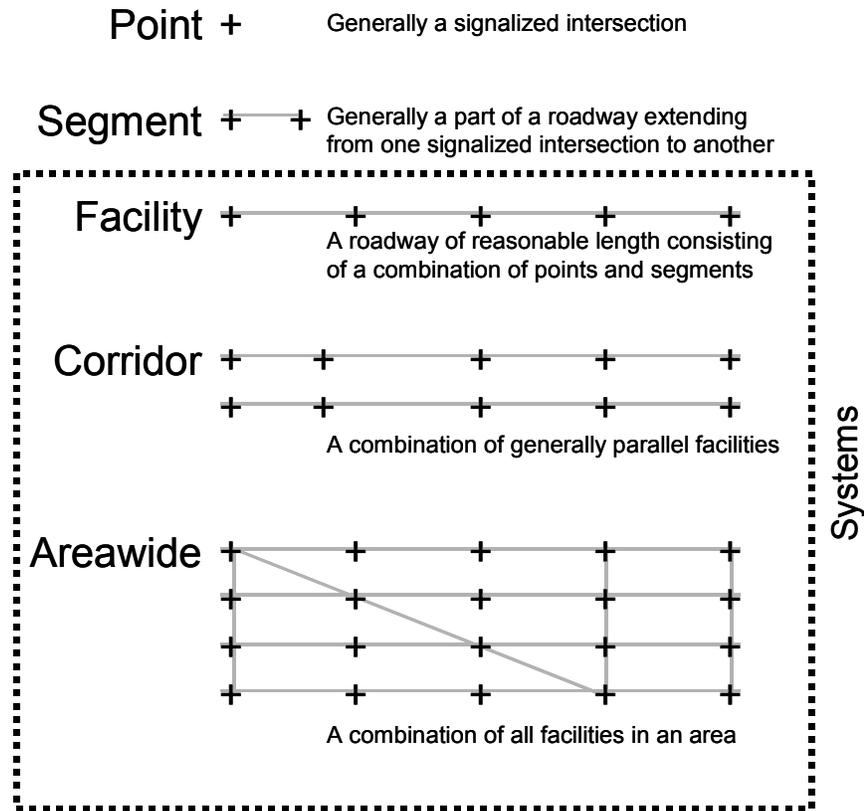


FIGURE 1 Definitions of highway segment and system (HCM 2000).

For the purposes of this synthesis, performance measures related to the operations of highway segments and systems (the facility, corridor, and areawide systems) defined by the HCM were evaluated.

### HOW DO YOU DEFINE PERFORMANCE MEASURES FOR THE OPERATIONAL EFFECTIVENESS OF HIGHWAY SEGMENTS AND SYSTEMS?

The report *Serving the American Public: Best Practices in Performance Measurement* (Office of Management and Budget 1996) recommends that a definition of a measure include

- A specific goal or objective from which it is derived;
- Data requirements, such as the population the metric, and will include the frequency of measurement, and data sources;
- The calculation methodology, including required equations and precise definition of key terms;
- Reports in which data will appear and the graphic presentation that will eventually be used to display data;
- Any other relevant rationale for the measure;

- A clear data collection plan that helps streamline the data collection process
  - Identify how much data needs to be collected, the population from which data will come, and the length of time over which to collect data.
  - Identify the charts and graphs to be used, the charting frequency, the type of comparison to be made, and the calculation methodology.
  - Identify the characteristics of data to be collected; attribute data are things that can be counted and variable data are things that can be measured.
  - Identify existing data sources or create new sources if the performance measure is new. All data sources need to be credible and cost-effective.

Common performance measures for the operational effectiveness of highway systems and segments and their definitions are identified in Table 1. In this table, the source of the measure was defined as either “Survey” (indicating it was a response to the survey of transportation agencies conducted in this research) or “TTI” [indicating the Texas Transportation Institute *Urban Mobility Report* (2001)]. This report is one of

TABLE 1  
COMMONLY USED PERFORMANCE MEASURES FOR THE OPERATIONAL EFFECTIVENESS OF HIGHWAY SYSTEMS AND SEGMENTS

Performance Measures	Typical Definition	Source	Planning Processes	Quality Initiatives	Respond to Legislative Mandates	ITS Evaluations	ITS Operations	Safety Management Systems	Congestion Management Systems	Public Information Programs	Driveway Permits	Responses (%)
Commercial vehicle safety violations	Number of violations issued by law enforcement based on vehicle weight, size, or safety	Survey	•			•	•	•		•		1.0
Congestion cost per capita	Annual “tax” per capita	TTI	•	•	•			•	•	•		
Congestion cost per eligible driver	Annual “tax” per driver	TTI	•	•	•			•	•	•		
Delay caused by incidents	Increase in travel time caused by incidents	Survey				•	•	•		•		3.0
Delay per capita	Annual time per person	TTI	•	•	•			•	•	•		
Delay per eligible driver	Annual time per driver	TTI	•	•	•			•	•	•		
Density	Passenger cars per hour per lane	Survey	•				•				•	3.0
Duration of congestion	Period of congestion	Survey	•	•	•	•	•	•	•	•		5.0
Evacuation clearance time	Reaction and travel time for evacuees to leave an area at risk	Survey	•	•	•	•	•	•	•	•		1.0
Incidents	Traffic interruption caused by a crash or other unscheduled event	Survey	•	•	•	•	•	•	•	•	•	6.0
Level of service (LOS)	Qualitative assessment of highway point, segment, or system using “A” (best) to “F” (worst) based on measures of effectiveness	Survey	•	•	•	•	•	•	•	•	•	11.0
Percent of system congested	Percent of miles congested (usually defined based on LOS E or F)	Survey	•	•	•	•	•	•	•	•	•	5.0
Percent of travel congested	Percent of vehicle-miles or person-miles traveled	Survey	•	•	•	•	•	•	•	•		4.0
Rail crossing incidents	Traffic crashes that occur at highway–rail grade crossings	Survey				•	•	•		•		3.0
Recurring delay	Travel time increases from congestion, but does not consider incidents	Survey	•	•	•	•	•		•	•		3.0
Response time to weather-related incidents	Period required for an incident to be identified and verified and for an appropriate action to alleviate the interruption to traffic to arrive at the scene	Survey				•	•	•		•		1.0

TABLE 1 (Continued)

Performance Measures	Typical Definition	Source	Planning Processes	Quality Initiatives	Respond to Legislative Mandates	ITS Evaluations	ITS Operations	Safety Management Systems	Congestion Management Systems	Public Information Programs	Driveway Permits	Responses (%)
Roadway congestion index	Cars per road space	TTI	•	•	•			•	•			
Security for highway and transit	Number of violations issued by law enforcement for acts of violence against travelers	Survey	•	•	•			•		•		1.0
Speed	Distance divided by travel time	Survey	•	•	•	•	•	•	•	•	•	7.0
Toll revenue	Dollars generated from tolls	Survey	•	•	•					•		1.0
Traffic volume	Annual average daily traffic, peak-hour traffic, or peak-period traffic	Survey	•	•	•	•	•	•	•	•	•	11.0
Travel costs	Value of drivers time during a trip and any expenses incurred during the trip (vehicle ownership and operating expenses, tolls, or tariffs)	Survey	•	•	•	•	•	•	•	•		3.0
Travel rate index	Amount of extra travel time	TTI	•	•	•			•	•	•		
Travel time	Distance divided by speed	Survey	•	•	•	•	•	•	•	•	•	8.0
Travel time reliability	Several definitions are used that include (1) variability of travel times, (2) percent of travelers who arrive at their destination within an acceptable time, and (3) range of travel times	Survey	•	•	•	•	•	•	•	•		1.0
Vehicle-miles traveled	Volume times length	Survey	•	•	•	•		•	•	•	•	10.0
Vehicle occupancy	Persons per vehicle	Survey	•	•	•				•	•		5.0
Wasted fuel per capita	Extra fuel due to congestion	TTI	•	•	•			•	•	•		
Wasted fuel per eligible driver	Extra fuel due to congestion	TTI	•	•	•			•	•	•		
Weather-related traffic incidents	Traffic interruptions caused by inclement weather	Survey				•	•	•		•		3.0

Notes: Percentages do not sum to 100% due to rounding.

the most commonly referenced sources of performance trends and conditions of congestion on the nation's highways. It provides basic system-level summary statistics of congestion in the nation's 78 largest metropolitan areas based on data provided from the Highway Performance Monitoring System (HPMS) and extrapolations of national derived assumptions.

Most performance measures used today are defined based on established programs such as the HPMS and the *Highway Capacity Manual* (various editions published since 1965). Recently, however, several performance measures have evolved for which no common definition is being used. One such area of particular importance is the travel reliability of highway segments and systems.

## WHAT ARE THE KEY STEPS IN PERFORMANCE-BASED MANAGEMENT?

The FHWA recently adopted the following key steps from the U.S. General Accounting Office, *Executive Guide: Effectively Implementing the Government Performance and Results Act* (1996, pp. 8–46.) for use in developing performance measures at the national level.

- Define mission and goals (including outcome-related goals)
  - Involve key stakeholders in defining missions and goals.
  - Identify key factors that could significantly affect the achievement of the goals.
  - Align activities, core processes, and resources to help achieve the goals.
- Measure performance
  - Develop a set of performance measures at each organizational level that demonstrate results, are limited to the vital few indicators for each goal at each organizational level, respond to multiple priorities, link to responsible programs, and are not too costly.
- Collect sufficiently complete, accurate, and consistent data to document performance and support decision making at various organizational levels.
- Report performance information in a way that is useful.
- Use performance information
  - Use performance information in systems for managing the agency or program to achieve performance goals.
  - Communicate performance information to key stakeholders and the public.
  - Demonstrate effectiveness or program performance.
  - Support resource allocation and other policy decision making.
- Reinforce performance-based management
  - Devolve decision making with accountability for results.
  - Create incentives for improved management and performance.
  - Build expertise in strategic planning, performance measurement, and use of performance information in decision making.
  - Integrate performance-based management into the culture and day-to-day activities of the organization.

## CURRENT STATE OF RESEARCH

Prior to the 1990s, research on performance measures was focused on the measures of effectiveness used by traffic engineers in highway capacity and quality of service studies. However, as congestion levels increased nationwide, many of these traditional measures of effectiveness became less meaningful. Concurrently, governments were seeking new ways of understanding trends and conditions of travel behavior and the operational effectiveness of the improvements they were making to the system. A third trend was the wider-scale implementation of intelligent transportation systems (ITS). The systems engineers and scientists who contributed to the ITS model deployments drew from their backgrounds in the use of performance measures to monitor performance and feedback systems. As a result of these new trends, interest in performance measures for operational effectiveness and research related to the science of performance measures applied to highway systems increased during the 1990s.

### SEMINAL WORKS

Some of the most influential research publications on the use of performance measures were published during the 1990s. These works defined needs for performance measures and outlined additional areas of research that were needed to better define performance measures, and to determine data requirements and reporting needs and methods. The following is a review of this work.

#### Performance Measures for Multimodal Transportation Systems

This report developed by Pratt and Lomax (1996) recommended the following principles when developing operational and planning performance measures and systems.

- *Match mobility performance measures with objectives*—Only if mobility performance measures are consistent with established goals and objectives for transportation and related systems can they be used to control the processes and achieve the desired results.
  - *Understand the effects of improvements*—The selected performance measures must quantify the effects of the anticipated range of improvement options for the full range of impacts to be understood.
  - *Address people and goods*—An important aspect of performance measures is the ability to identify their effects on the movement of people and goods and on the achievement of travel and shipping objectives.
  - *Use common denominators*—To facilitate comparisons within multimodal systems, common denominators such as speed, acceptable travel time, and person throughput are needed.
  - *Development of measures should not be governed by data concerns*—The availability of data and analysis procedures should not be considered in the process of identifying the best possible set of performance measures. After the performance measures are identified, they should act as a starting point for the process.
  - *Employ both multimodal and mode-specific measures*—Multiple transportation modes need to be measured together, to analyze the total effect, and separately, to identify individual deficiencies.
  - *Remember the audience*—The knowledge basis and levels of interest of the various users of transportation performance measures are different and must be considered if measures are to satisfy communication needs.
- In the study, *Measures of Effectiveness for Major Investment Studies*, Turner et al. (1996) identified measures of effectiveness that can be used to compare the benefits and impacts of transportation improvements for a major investment study. These candidate measures were qualitatively evaluated according to the following criteria:
- Applicability to individual and aggregate transportation modes,
  - Ease of measure for calculation and analysis,
  - Accuracy of measurement results,
  - Clear and consistent interpretation of results, and
  - Clarity and simplicity.
- Table 2 identifies the performance measures recommended for major investment studies in this report. The researchers concluded that the following significant factors should be considered when selecting measures of effectiveness for a major investment study:
- Match the measures with the goals and objectives of the study;
  - Develop and select the measures early in the study with key input from local decision makers;
  - Use a comprehensive set of measures, but do not substantially duplicate or restate benefits or impacts;
  - When possible, quantify impacts and do not simply use subjective judgment;

TABLE 2  
PERFORMANCE MEASURES FOR EVALUATING THE IMPACT OF  
TRANSPORTATION IMPROVEMENTS

Area of Impact	Performance Measures
Transportation performance	Average travel time Average travel rate Total delay Person-miles of travel in congested ranges Person-hours of travel in congested ranges Person movement Person movement speed Accident reduction
Financial/economic performance	Benefits/costs ratio (using full-cost analysis) Financial feasibility Cost per new person-trip
Social impacts	Number of displaced persons Number and value of displaced homes Neighborhood cohesion Accessibility to community services
Land use/economic development impacts	Number and value of displaced businesses Accessibility to employment Accessibility to retail shopping Accessibility to new/planned development sites
Environmental impacts	Energy consumption Mobile source emissions Noise levels Visual quality/aesthetics Vibration Water resources Wildlife/vegetative habitat Parkland/open/green space Cultural resources Agriculture/forest resources Geologic resources Hazardous wastes

- Provide perspective on the magnitude of the impacts; and
- Identify error levels of calculation in relation to the measure values.

#### Alternative Performance Measures for Transportation Planning: Evolution Toward Multimodal Planning

This research project by Meyer (1995) examined key characteristics of performance-based transportation planning. Several illustrations of planning as it was evolving at the time were presented and the following observations were made.

- *System performance is a concern*—System performance can be defined based on what is important to the (1) owner and (2) the user of the transportation system. Both types of measures are needed and should be distinguished.
- *Measures must be tied to the roles of transportation*—The application of performance measures to systems versus small elements of the transportation system should be distinguished and the linkages between element and system performance must be made. Therefore, core values and goals must be identified and measures should be linked to specific goals and objectives. A family of measures is required to ensure that the role of transportation is fully described.
- *Outcomes and outputs*—Performance measures should relate to outcomes describing cause-and-effect relationships that involve owners and users. Outcome measures relate to the quality of life, safety, environmental quality, and economic opportunities. Performance measures should also relate to output measures, which are indicators of the direct production of an organization, such as lane-miles constructed.
- *Mobility and accessibility*—Both mobility and accessibility should be considered. As part of this approach, the distribution of benefits to users and the

TABLE 3  
HIGHWAY SEGMENT AND SYSTEM PERFORMANCE MEASURES

Facility Type	Performance Measures
Basic freeway section	Density (passenger cars per hour per lane)
Weaving area	Density
Ramp junctions	Density
Freeway facilities	Average vehicle speed
Multilane highways	Density
Two-lane highways	Percent time delay
Signalized intersections	Average vehicle delay
Unsignalized intersections	Average vehicle delay
Arterials	Average vehicle speed
Interchanges	Average vehicle delay

potential to increase the demand for services should be studied.

- *Travel time as a key indicator*—A total trip travel time was recommended for use. It has the strongest fundamental link between user perception and the mobility provided.
- *Performance measures should be tied to project evaluation criteria*—Similar to the need to tie performance measures to the values, goals, and objectives of the users of the system, performance measures should relate to the criteria established in project evaluations.
- *A strategic data collection and management plan is essential*—The success of performance measures is tied directly to the quality and quantity of data. Therefore, a critical element in implementing performance measures is the development of a strategic data collection program identifying the methodologies, techniques, standards, and frequency of data collection.
- *Development of new analysis tools*—New analysis tools are required that can report data and measures in ways that are easily understood by engineers, planners, elected officials, and users of the transportation system.

Techniques for selecting performance measures and recommendations on data collection frequencies were also provided. This report examined the incorporation of mobility and accessibility concerns in transportation planning, which included

- How is system performance defined and who defines it?
- What are the differences between an “output” and an “outcome”?
- What are the most appropriate performance measures?
- How should performance measures be used?
- What are the implications of performance-based planning on data collection and on the types of analysis tools that are available to transportation planners?
- How do performance measures relate to the goals, objectives, and measures of effectiveness?

The research was based on extensive case studies of state DOTs, MPOs, and transit planning agencies’ efforts related to performance-based planning. The following summarizes the key findings:

- Mobility and accessibility should be important measures of system performance.
- Travel time and modal availability should be the foundation for mobility performance measures.
- Accessibility measures should be incorporated into project planning and system evaluation approaches.
- Market segmentation and distributional effects of mobility and accessibility changes should be part of measuring system performance.

#### Performance Measures for Highway Capacity Analysis

This research project by May developed mobility performance measures and level of service (LOS) criteria for the year 2000 edition of the *Highway Capacity Manual* (HCM). The project recommended vehicle- and person-trip time and delay as the primary systemwide performance measure for highway segments and systems. A methodology was recommended for combining analyses using the HCM’s procedures to aggregate these measures to the system level. The measures recommended for highway segments are summarized in Table 3.

#### Quantifying Congestion (Volumes 1 and 2)

This report, prepared by Lomax et al. (1997), was one of the first nationally accepted research documents on performance measures. The report addressed the following purposes for performance measures:

- Monitoring needs and studies,
- Design analyses and operational analyses,
- Evaluation of alternatives,
- Establishing base conditions and setting priorities,

TABLE 4  
CROSS-CLASSIFICATION OF THE USES OF CONGESTION MEASURES

Purposes for Which Congestion Measures Are Used	Monitoring and Needs Studies	Design and Operational Analysis	Evaluation of Alternatives	TDM, TSM, TCM, and Policy Studies	Development Impact Evaluation	Route and Travel Choice	Education
Identification of problems	•	•	•	•	•	•	•
Basis for government action/investment/policies	•	•	•	•	•		•
Setting of improvements priorities	•		•	•			•
Information for private sector decisions	•	•	•	•	•	•	•
Basis for national, state, and regional policies and programs	•			•	•		•
Assessment of traffic controls, geometrics, laneage, and regulations		•	•				•
Assessment of transit routing, scheduling, and stop placement		•	•				•
Base case (for comparison of alternatives)	•	•	•	•	•	•	•
Inputs for transportation models			•	•	•	•	•
Inputs for air quality and energy models		•	•	•	•		•
Measures of effectiveness for alternatives evaluation		•	•	•	•	•	•
Measures of impact of land development				•	•		•
Input to zoning decisions					•		•
Basis for real-time route choice decisions						•	•

Notes: TDM = travel demand management; TSM = transportation systems management; TCM = transportation control management.

- Developing impact evaluations,
- Commercial vehicle scheduling, and
- Education.

These purposes were then cross classified with specific applications in the transportation planning process as shown in Table 4.

This report recommended the following dimensions of congestion:

- Duration (temporal),
- Extent (geographic),
- Intensity (severity), and
- Reliability (variation).

The specific performance measures recommended in this research are as follows:

- Travel rate (minutes per mile), 60 min divided by the speed in miles per hour (mph);
- Delay rate (minutes per mile), minutes of delay divided per mile;
- Total delay (person-hours), sum of all person delay;
- Relative delay rate (dimensionless), delay rate divided by desired travel rate;

- Delay ratio (dimensionless), delay rate divided by actual travel rate;
- Speed of person movement (persons-mph), persons times speed;
- Corridor mobility index (dimensionless), speed of person movement divided by a normalizing value;
- Accessibility (percent), percent of destinations within  $x$  minutes;
- Accessibility (minutes), mean travel time to all destinations; and
- Congested travel (person-miles), sum of congested lengths times persons.

#### Planning Techniques for Estimating Speed and Level of Service

This NCHRP Project 3(55) and its companion, *Planning Applications for the Year 2000 Highway Capacity Manual* [NCHRP Project 3(55)2-A], prepared by Dowling et al. are authoritative references on the techniques for estimating speed and other “prime” performance measures needed in any estimating or modeling techniques. These reports contain a number of alternative techniques and recommend various approaches for implementing performance measures in planning practice.

## RECENT ADVANCES IN RESEARCH

Most research related to operational performance measures published since the mid-1990s has extended these concepts and explored and recommended techniques for describing specific measures. Recent areas of research emphasis include reliability of operations and transportation systems and multimodal performance measures.

### Reliability Performance Measures

Jackson et al. (2000) published *Florida's Reliability Method*, which included a recent survey of reliability performance measures used nationally, compared and assessed the strengths and weaknesses of reliability performance measures identified in research and through the practices of transportation agencies for planning and operations, and recommended reliability performance measures for use by the Florida DOT. The following review of alternative reliability performance measures was adapted from this report.

Historically, reliability has been associated with the performance of mechanical equipment or devices. In this context, reliability is defined as “the probability of a device performing its purpose adequately for the period of time intended under the stated operating conditions.” However, reliability from a transportation system perspective has been defined in different ways by different researchers. The following definitions of reliability have been documented in the literature:

- The likelihood of a traveler’s expectations being met. Reliability is measured as the variability between the expected travel time (based on scheduled or average travel time) and the actual travel time (due to the effects of nonrecurrent congestion);
- The range of travel times experienced during a large number of daily trips; and
- The impact of nonrecurrent congestion on the transportation system, estimated as a function of the variation in the duration, extent, and intensity of traffic congestion on a system.

These definitions suggest that reliability is an indicator of the operational consistency of a facility over an extended period of time, measured as some function of the amount of recurrent and nonrecurrent delay that occurs over that period.

Just as a number of definitions are available for reliability, a wide range of techniques is reported for measuring reliability.

In *Measures of Effectiveness for Major Investment Studies*, Turner et al. (1996) define trip time reliability as the

range of travel times experienced during a large number of daily trips. The range of travel times can be obtained by calculating the mean and standard deviation of travel times within a sample. For example, an uncongested facility might have a trip time reliability of 12 to 15 min for 85% of all trips, whereas on a congested facility the reliability might be between 20 and 30 min. This method was used in a recent study documenting the travel time savings and reliability benefits of high-occupancy vehicle (HOV) lanes over freeway main lanes. Lomax et al. (2000) suggest that this method can be used to calculate reliability for a variety of roadway systems, including single roadways, corridors, and areawide networks.

However, the range of travel times itself is not very meaningful unless it is used to make comparisons of conditions along the same facility (e.g., northbound versus southbound travel, or HOV lane versus general-use lane travel). The range of travel times is also based on a fixed benchmark using the 85th percentile. The result is that the proportion of unreliable travel would always stay approximately the same. For example, using the 85th percentile, approximately 15% of the travel time observations would always be considered unreliable, regardless of the number of observations, the value of the mean travel time, or the standard deviation of travel time. This concept is depicted in Figure 2.

This technique also involves a two-tail test, in which unreliable conditions are considered to be those in which the travel time is either significantly better or significantly worse than average conditions. However, it is intuitive that a traveler would benefit from significantly better conditions, so that unreliable conditions should be those in which travel times are significantly worse than what is expected. The area of concern is the right tail of the distribution; therefore, a one-tail test is more appropriate. This concept is depicted in Figure 3.

Lomax et al. (2001) proposed that reliability could be measured as the difference in delay experienced on incident days versus nonincident days. Total delay is the amount of time lost due to congestion on a roadway segment and can be calculated using this equation.

$$\text{Total Segment Delay (veh-min)} = \left[ \begin{array}{cc} \text{Actual} & \text{Acceptable} \\ \text{Travel Time} & - \text{Travel Time} \\ \text{(min.)} & \text{(min.)} \end{array} \right] \times \text{Vehicle Volume (veh)}$$

The acceptable travel time is the total travel time it would take to travel a segment during expected conditions. This travel time is generally calculated assuming travel at the posted speed limit, although it may also be calculated using a congestion threshold speed established from local

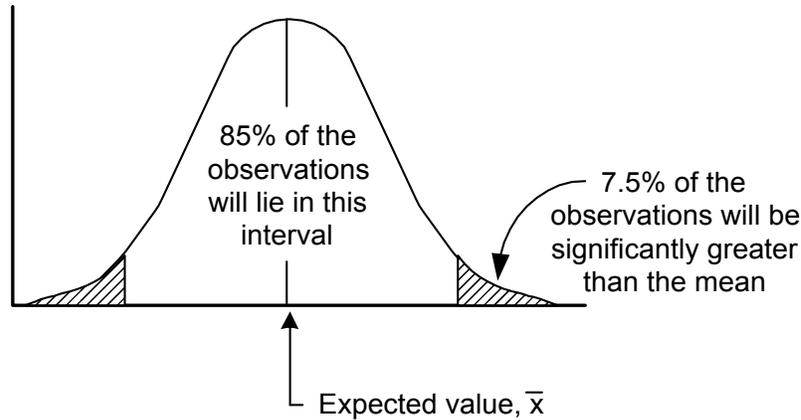


FIGURE 2 Illustration of two-tail test with a fixed benchmark.

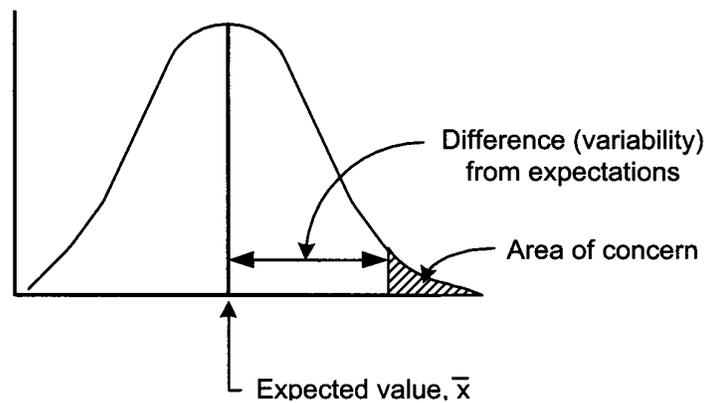


FIGURE 3 Illustration of a one-tailed test.

performance goals for mobility. Total delay along a corridor is calculated as the sum of the vehicle-minutes of delay on the individual segments of that corridor.

This technique for measuring reliability does not consider both recurrent and nonrecurrent delay. It is widely regarded that the travel time even on nonincident days may be far from acceptable.

Ikhtrata and Michell (1998) define reliability as the probability that users will arrive at their destinations within the expected (average) travel time. They developed a reliability performance indicator,  $R$ , for the Southern California Association of Governments, which can be calculated as follows:

$$R = 1 - (\% \text{ trips}_{\text{within}} - \% \text{ trips}_{\text{exceed}})$$

where

$\% \text{ trips}_{\text{within}}$  = the percent of trips in which users arrive at their destinations at the expected (average) travel time or less; and

$\% \text{ trips}_{\text{exceed}}$  = the percent of trips in which users do not arrive at destinations within the expected (average) travel time.

Ikhtrata and Michell anticipate that the reliability performance indicator can be calculated using commuter survey data available through the annual State of the Commute and Census Transportation Planning Package. However, the indicator is theoretical in nature, and the association is continuing to explore other concepts of reliability.

A preliminary investigation of this methodology revealed that because the indicator is based on the average travel time, approximately one-half of the observations will always fall within the average value and one-half will exceed it. Using this methodology, the reliability performance indicator will always have a value in the range of 0.9 to 1.1. Further examination revealed that even if the methodology was refined to incorporate a benchmarking method the value of the reliability performance indicator will increase as conditions become less reliable.

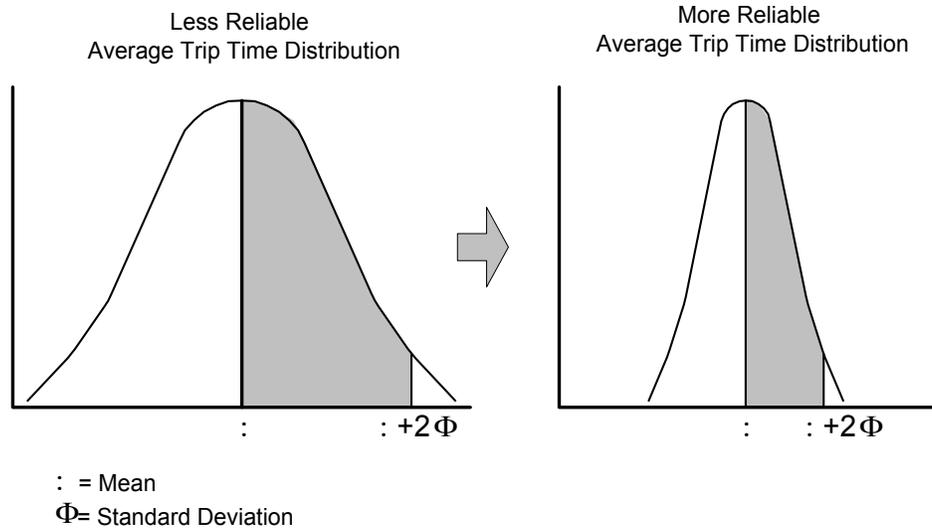


Figure 4 Illustration of California reliability measure.

The *1998 California Transportation Plan* (1998) defines reliability as the variability between the expected travel time (based on scheduled or average travel time) and the actual travel time (due to the effects of nonrecurrent congestion). “Reliable” segments are those in which travel time over the segment does not vary significantly from day to day. “Unreliable” segments have highly variable travel times. This concept is visually depicted in Figure 4.

The coefficient of variation describes the dispersion or variability of travel time, but does not really indicate how well conditions on the corridor meet travelers’ expectations.

Rakha and Van Aerde (1995) examined the variability in traffic conditions during both typical nonincident conditions and incident conditions. The researchers attempted to identify typical weekday traffic conditions by establishing average typical conditions and then estimating the upper and lower bounds of these average conditions. This establishes average weekday statistical confidence limits based on the 95th percentile. Preliminary investigations revealed that use of the 95th percentile will only reflect the variability associated with crashes (nonrecurrent congestion) that occurred along the corridor. Additionally, it will not necessarily reflect the influence of crashes on traffic conditions in a consistent manner. The calculations associated with this technique also involve more complexity than other reliability methods.

The *Florida’s Reliability Method* report (Jackson et al. 2000) went further to derive a methodology for determining reliability from the Florida DOT’s definition of the reliability of a highway system as the percent of travel on a corridor that takes no longer than the expected travel time plus a certain acceptable additional time. In this context, it is necessary to define the three major components of reliability.

1. Travel time—The time it takes a typical commuter to move from the beginning to the end of a corridor. Because speed is determined along each segment as the traveler moves through the corridor, this travel time is a function of both time and distance. This is representative of the typical commuter’s experience in the corridor.
2. Expected travel time—The median travel time across the corridor during the time period being analyzed. The median is used rather than the mean so that the value of the expected travel time is not influenced by any unusual major incidents that may have occurred during the sampling period. These major incidents will be accounted for in the percentage of how often the travel takes longer than expected, but will not change the baseline to which that unusually high travel time is being compared.
3. Acceptable additional time—The amount of additional time ( $\Delta$ ), beyond the expected travel time, that a commuter would find acceptable during a commute. The acceptable additional time is expressed as a percentage of the expected travel time during the period being analyzed. Times 5%, 10%, 15%, and 20% above the expected travel time are currently being considered. However, Florida practice recommended that preference surveys be conducted to determine how much difference from the expected commute a traveler would find acceptable. The Minnesota DOT recently completed its first such survey and found that acceptable delay tended to be an absolute number of minutes, regardless of travel distance for intercity travel and not a percent of travel time.

The threshold when travel exceeds the acceptable additional time beyond the expected travel time is obtained using the following equation:

$$\text{Acceptable } TT = \bar{x} + \Delta$$

where

- $\bar{x}$  = the median travel time across the corridor during the period of interest; and
- $\Delta$  = an additional travel time estimated as a percentage of the median travel time during the period of interest or value, used to establish the additional time beyond the expected travel time that a traveler would find acceptable.

The percent of reliable travel is calculated as the percent of travel on a corridor that takes no longer than this acceptable travel time.

A comparative analysis was conducted using traffic flow data for the following three study corridors: (1) I-95 in Jacksonville, (2) I-95 in Broward County, and (3) I-4 in Orlando. Two test corridors were also included in the project. The first test corridor was I-95 from south of Hallandale Beach Boulevard in Broward County to north of Yamato Road in Palm Beach County. Data for this corridor were collected as part of a 1999 Interstate Traffic Data Survey. The second test corridor was a 23-mi segment of I-405 in Seattle, Washington.

The reliability results suggest that the Florida Reliability Method is well suited for measuring reliability because it characterizes reliability as an indicator of how well conditions on the corridor meet travelers' expectations by establishing an acceptable travel time unique to the corridor. This definition matches well with the reliability definitions provided by operations researchers and used in other commercial transportation applications such as aviation (on-time arrivals), rail (on-time arrival), and integrated logistics (on-time or just-in-time delivery). Other methods describe the variability of travel time but do not report directly on reliability from this perspective.

The following recommendations were made regarding data collection for reliability measurement:

- For the calculation of reliability using the Florida Reliability Method, the acceptable additional time should be based on a fixed percentage of 15 or 20% of the expected travel time. However, it is recommended that preference surveys be conducted to determine how much difference from the expected commute a traveler would find acceptable.
- Reliability should be measured for a consistent peak hour (such as 5 to 6 p.m.) rather than the peak period for a corridor. This allows comparisons between facilities, and also enables annual monitoring of reliability on the same facility, because the peak period may change from year to year.

- The interval for collecting speed and volume data should be less than the travel time under free-flow conditions.
- The optimum data collection period for the reliability measurement is a 6-week period using data collected at intervals of 5-min or less based on the travel time under free-flow conditions as noted above.
- Data collected over a 4-week period at 15-min intervals is the minimum recommended to provide an adequate sample size.

As part of the *Urban Mobility Report: 2000*, prepared by the Texas Transportation Institute (TTI) (Lomax et al. 2001), a reliability buffer index was introduced in 2002 that estimates the difference between the average travel time and the 95th percentile travel time as the extra time that has to be budgeted for a trip compared with the average travel rate to define a reliability index. In the middle of the evening peak, the sources of travel time variation are so significant that an extra 2 min per mile should be budgeted as the buffer, in addition to the average travel time of 1.5 min per mile.

Buffer Index ( $BI$ ) = [95th percent confidence travel rate – average travel rate] / [average travel rate] × 100%

This index assumes that the 95th percentile travel rate (minutes per mile) is the acceptable threshold for trip making by the user. As explained by the author

What does all this mean? If you are a commuter who travels between about 7:00 a.m. and 9:00 a.m., your trip takes an average of about 30 percent longer (that is, the TTI value is 1.3) than in the off-peak. A 20-mile, 20-minute trip in the off-peak would take an average of 26 minutes in a typical home-to-work trip. The Buffer Index during this time is between 50 and 100 percent, resulting in a Trip Planning Time of 2.1 minutes per mile. So, if your boss wants you to begin work on time 95 percent of the days, you should plan on 42 minutes of travel time (20 miles times an average of 2.1 minutes per mile of trip for the peak period). But, to arrive by 8:00 a.m., you might have to leave your home around 7:00 a.m. because the system is even less reliable in the period between 7:30 a.m. and 8:00 a.m.

Although this concept is close to the user's perception of reliability, it assumes that the only trips that are unreliable are the last five percentage trips, and indirectly reports on the reliability as illustrated in the authors definition. The construct is flexible enough to allow using an alternate percentile trip for the threshold of acceptable performance. However, operations research has shown the percent of trips accomplished within an "acceptable time" is a more direct measure of reliability as experienced by the user.

#### Multimodal Performance Measures

The *Multimodal Corridor and Capacity Analysis Manual* (Cambridge Systematics et al. 1998) identifies performance

measures applicable to both users and nonusers of the transportation system, as well as measurement of the transportation facility itself. The following quantitative and qualitative performance measures apply to users of the transportation system:

- Service frequency,
- Travel time,
- Travel comfort,
- Travel time reliability,
- Probability of loss and/or damage, and
- Costs.

Performance measures applicable to nonusers of the transportation system include the following:

- Congestion costs,
- Noise,
- Fuel consumption,
- Emissions,
- Pavement maintenance costs, and
- Bridge maintenance costs.

Transportation facilities can be measured by the following aggregate measures:

- Volume/capacity (V/C) ratio for vehicles;
- V/C ratio for persons;
- V/C ratio for goods moved expressed in any of the following units—weight, cubic volume, or equivalent equipment movements such as truckload equivalent units;

- Speed on facilities and through nodes (time mean speed, space mean speed, and variability);
- LOS for key facilities and sources of delay;
- Cumulative person-hours of delay;
- Cumulative hours of delay for freight;
- Dollar value of cumulative delay for persons and freight;
- Cumulative delay by the most important delay sources (noncongestion-related delays, congestion-related delays, recurring delays, and nonrecurring delays);
- Passenger and freight vehicle-mile traveled (VMT) on a facility;
- Additional trips on a facility; and
- Accidents (persons and freight).

The *Multimodal Corridor and Capacity Analysis Manual* reported that regardless of which performance measures are chosen, the most important indicator of performance is the volume of traffic on the facility relative to capacity (V/C ratio). From a multimodal perspective, the V/C ratio is an indicator of the supply and demand for a facility and can be expressed in vehicles, persons, or goods moved. The V/C ratio can be measured over various aggregations of time to approximate performance measures. Examples of time aggregations include the V/C ratio during the peak-hour, peak-period, off-peak, 12-h, 18-h, and daily V/C.

Performance measures based on the impact of queuing and peak spreading on travel time were also identified as being needed. However, no specific methodologies were identified.

TABLE 5  
PERFORMANCE MEASURES COMPARISON CRITERIA

General Criteria	Specific Criteria
Clarity and simplicity	The measure is simple to present, analyze, and interpret The measure is unambiguous The measure's units are well defined and quantifiable The measure has professional credibility Technical and nontechnical audiences understand the measure
Descriptive and predictive ability	The measure describes existing conditions The measure can be used to identify problems The measure can be used to predict change and forecast condition The measure reflects changes in traffic flow conditions only
Analysis capability	The measure can be calculated easily The measure can be calculated with existing field data There are techniques available to estimate the measure The results are easy to analyze The measure achieves consistent results
Accuracy and precision	The accuracy level of the estimation techniques is acceptable The measure is sensitive to significant changes in assumptions The precision of the measure is consistent with planning applications The precision of the measure is consistent with an operation analysis
Flexibility	The measure applies to multiple modes The measure is meaningful at varying scales and settings.

Adapted from Meyer (1995), Turner et al. (1996), Lomax et al. (1997), and Jackson et al. (2000)

**SUMMARY**

Research in performance measures for the operational effectiveness of highway segments and systems has evolved over the last 10 years. Seminal works established the common principles for performance measurement that build on successful practices and use professionally accepted techniques for measuring and estimating measures of effectiveness. More recent works define and support new measures in the areas of reliability and multimodal operations in the highway environment. These works have many common themes for defining and determining when performance measures are effective tools. Table 5 synthesizes many of these basic principles and will be used in chapter five in discussing the strengths and weaknesses of measures identified in chapter four.

However, continuing research is needed that emphasizes highway operational effectiveness from the travelers' perspective and how to better link performance measures to operational improvements so that efficiency gains can be achieved similar to those that occurred in the aviation industry in the 1980s. For this to occur, a paradigm shift is needed throughout all transportation agencies that are involved in the planning, design, construction, or operations of the highways to address a total systems and operational management approach throughout the life cycle of highway operational and ITS improvements. Several state transportation agencies, MPOs and local transportation authorities have embarked on this transformation and their practices are highlighted in chapter four.

## CURRENT STATE OF THE PRACTICE

A survey of state transportation agencies and MPOs was conducted in September of 2001. Thirty-five agencies responded to the survey. Nineteen of the respondents were state DOTs, with the remaining 16 agencies MPOs. Eighty-five percent of the responses were received from planning offices within these agencies, whereas only 15% of the responses were received from operation's offices. Eighty percent of the agencies in areas with populations of more than 500,000 responded that they use performance measures. The major results of the survey may indicate

- Performance measures were reported less frequently in an operational environment. This may be a product of the survey being directed to planning units in the organizations from TRB's primary organization contact. Planning-related performance measure programs typically have more visible performance measure programs in the agency. In either case, the results of the survey may be biased to performance measures in the planning arena rather than the operations environment.
- Agencies in larger (population) areas are more likely to have a performance measure program in place. This may be a result of the resources available to larger agencies or that these agencies have more complex congestion and mobility issues to manage that may not be adequately addressed by more traditional measures of effectiveness such as LOS.
- There are opportunities for improvements in transportation operations. Many agencies have not formally adopted performance measures, but rely solely on experience and intuition to understand the conditions that exist on the system or to evaluate alternative strategies for improving operations.
- *and the measures derived by legislators or through rules implementing the measures in the transportation agency.*
- *Planning processes, including budget and funding allocations*—These programs are usually tied to transportation policies and objectives and reported at the macroscopic level. The performance measures are included in the plans themselves or referred to as mobility performance measures. Increasingly, performance measures are being mainstreamed in agency strategic plans and long-range transportation plans.
- *Quality initiatives*—These activities are directed at improving the quality of the delivery of services by the agency to the users of transportation services. They are typically related to Deming Quality Initiatives, Total Quality Management Programs, Sterling Quality Initiatives, or the International Standards Organization's Standard 9001 efforts.
- *Congestion management systems and evaluation*—Many agencies have continued with the transportation management programs established by ISTEA and report on the progress of relieving congestion and evaluating alternatives for implementation.
- *ITS operations and evaluations*—These performance measures are intended to evaluate the benefits of providing ITS and are typically a mix of output measures and operational-related outcome measures.
- *Safety management systems*—Many agencies have continued with the transportation management programs established in ISTEA and report on the progress of making facilities safer.
- *Permit processes for commercial driveways*—Agencies use performance measures such as LOS to assess permits for driveways along highway segments.

### HOW ARE PERFORMANCE MEASURES BEING USED?

A wide range of possible applications for performance measures was reported in the research. However, the results of the survey of state DOTs and MPOs revealed that performance measures are primarily used for the following purposes:

- *Responding to legislative mandates*—There is an increasing emphasis for organizations to be accountable to legislatures or other oversight boards for the efficacy of expenditures on transportation programs. These programs are usually mandated for annual reporting

### WHAT PERFORMANCE MEASURES ARE USED?

A wide range of performance measures is currently used. Table 6 summarizes the performance measures that are used by the survey respondents and their potential application areas. The measures used by the TTI in the *Urban Mobility Report* (Lomax et al. 2001) developed each year on the nation's 68 largest urbanized areas are also commonly used (Table 7). These measures are reported annually and are commonly referenced by the media and in planning studies to compare congestion between areas. Any synthesis of performance measures for operational effectiveness of highways would be remiss without summarizing the

TABLE 6  
PERFORMANCE MEASURES AS REPORTED IN THE SURVEY OF STATE DOTs AND MPOS

Performance Measure	Typical Definition	Responses
Level of service (LOS)	Qualitative assessment of highway point, segment, or system using A (best) to F (worst) based on measures of effectiveness	11.0
Traffic volume	Annual average daily traffic, peak-hour traffic, or peak-period traffic	11.0
Vehicle-miles traveled	Volume times length	10.0
Travel time	Distance divided by speed	8.0
Speed	Distance divided by travel time	7.0
Incidents	Traffic interruption caused by a crash or other unscheduled event	6.0
Duration of congestion	Period of congestion	5.0
Percent of system congested	Percent of miles congested (usually defined based on LOS E or F)	5.0
Vehicle occupancy	Persons per vehicle	5.0
Percent of travel congested	Percent of vehicle-miles or person-miles traveled	4.0
Delay caused by incidents	Increase in travel time caused by an incident	3.0
Density	Vehicles per lane per period	3.0
Rail crossing incidents	Traffic crashes that occur at highway-rail grade crossings	3.0
Recurring delay	Travel time increases from congestion; this measure does not consider incidents	3.0
Travel costs	Value of driver's time during a trip and any expenses incurred during the trip (vehicle ownership and operating expenses or tolls or tariffs)	3.0
Weather-related traffic incidents	Traffic interruption caused by inclement weather	3.0
Response times to incidents	Period required for an incident to be identified, verified, and for an appropriate action to alleviate the interruption to traffic to arrive at the scene	2.0
Commercial vehicle safety violations	Number of violations issued by law enforcement based on vehicle weight, size, or safety	1.0
Evacuation clearance time	Reaction and travel time for evacuees to leave an area at risk	1.0
Response time to weather-related incidents	Period required for an incident to be identified, verified, and for an appropriate action to alleviate the interruption to traffic to arrive at the scene	1.0
Security for highway and transit	Number of violations issued by law enforcement for acts of violence against travelers	1.0
Toll revenue	Dollars generated from tolls	1.0
Travel time reliability	Several definitions are used that include (1) variability of travel times, (2) percent of travelers who arrive at their destination within an acceptable time, and (3) range of travel times	1.0

measures of effectiveness used in the HCM. The HCM is considered the international authority on the analysis of highway segments and systems in operations and planning. Table 8 summarizes the measures of effectiveness (performance measures used to determine LOS in the HCM).

#### WHICH MEASURES ARE MOST IMPORTANT TO AGENCIES?

Because of the wide range of performance measures being used, a primary question is: what measures are more important to the agencies using them? The following section summarizes the survey responses.

Measures of the number of persons or vehicles served were most commonly reported as the most important measures, including

- Volume,
- VMT,

- Persons-served expressed in person-miles traveled, and
- Freight-volume served expressed in truck-miles traveled.

Use of these quantity measures for operational effectiveness does not relate to the quality of the traveling experience but to the magnitude of the persons, vehicles, or freight served. These measures are important for transportation agencies because many agency's goals and objectives include maximizing the number of persons, vehicles, or freight served at a given performance level. For example, if a transportation agency decides to add lanes to a highway, it is likely that it may continue to operate at capacity during the peak hour, but more persons, vehicles, and freight are served.

The quantity measures were cited as the most important for their ease in collection and reporting and the ability to derive other measures from these basic measures. Examples of the measures that can be derived from these measures include

TABLE 7  
TEXAS TRANSPORTATION INSTITUTE’S CONGESTION MEASURES IN THE *URBAN MOBILITY REPORT*

Measure	Definition	Calculation Method
Roadway congestion index	Cars per road space	$\frac{\frac{VMT_{Freeway}}{Lane - mile_{Freeway}} \times VMT_{Freeway} + \frac{VMT_{Arterial}}{Lane - mile_{Arterial}} \times VMT_{Arterial}}{13,000 \times VMT_{Freeway} + 5,000 \times VMT_{Arterial}}$
Travel rate index	Amount of extra travel time	$\frac{\frac{60 / Speed_{Freeway}}{60 / FreeflowSpeed_{Freeway}} \times VMT_{Freeway} + \frac{60 / Speed_{Arterial}}{60 / FreeflowSpeed_{Arterial}} \times VMT_{Arterial}}{VMT_{Freeway} + VMT_{Arterial}}$
Delay per eligible driver	Annual time per driver	Total delay (includes recurring and incident delay) per eligible driver
Delay per capita	Annual time per person	Total delay (includes recurring and incident delay) per person
Wasted fuel per eligible driver	Extra fuel due to congestion	Difference between fuel consumption in existing conditions and fuel consumption based on free-flow speeds per driver
Wasted fuel per capita	Extra fuel due to congestion	Difference between fuel consumption in existing conditions and fuel consumption based on free-flow speeds per driver
Congestion cost per eligible driver	Annual “tax” per driver	Costs in dollars of congestion based on comparison of existing conditions and free-flow conditions per eligible driver
Congestion cost per capita	Annual “tax” per capita	Costs of congestion based on comparison of existing conditions and free-flow conditions per eligible driver

TABLE 8  
HIGHWAY SEGMENT AND SYSTEM PERFORMANCE MEASURES

Facility Type	Performance Measures
Basic freeway section	Density (passenger cars per hour per lane)
Weaving area	Density
Ramp junctions	Density
Freeway facilities	Average vehicle speed
Multilane highways	Density
Two-lane highways	Percent time delay
Signalized intersections	Average vehicle delay
Unsignalized intersections	Average vehicle delay
Arterials	Average vehicle speed
Interchanges	Average vehicle delay

(Adapted from *Highway Capacity Manual 2000*).

- Fuel consumption,
- Noise impacts, and
- Air quality impacts.

It should be noted that the measures that were reported as the most important to the agency may or may not be the most important to the users of the transportation system. Several of the research and transportation agencies evaluated in this synthesis reported the need to better define what measures are the most important to the users. Strategies such as stated-preference surveys and psychometric studies were identified as potential techniques to better determine what performance measures and operational characteristics are most important to the users.

The following measures were also identified as indicators of congestion levels.

- Measures of the quality of travel or congestion levels were the second most commonly reported most important measures. Examples of these measures included
  - V/C,
  - Delay,
  - LOS,
  - Speed, and
  - Travel time.
- Other measures that were reported as the most important included

- Safety measures
  - Crashes or incidents per million VMT, and
  - Severity of crashes (fatality, injury, or property damage).
- Reliability,
- Efficacy of freight movements,
- Capital costs in proportion to travel time,
- Accessibility,
- Environmental
  - Air quality, and
  - Noise.
- Equity/environmental justice,
- Cost-effectiveness,
- Vehicle occupancy and HOV lane performance,
- Pavement and bridge condition,
- Percent of system congested,
- Number of miles operating at desired speed ranges,
- Queuing of traffic,
- Performance measures derived from ITS data
  - Predictability of travel times,
  - Reliability of travel times,
  - Number of incidents,
  - Number of stops for assistance,
  - Number of stops served by service patrols,
  - Incident response times, and
  - Percent of ITS equipment operational.
- Customer satisfaction (users and partners)
  - Ease of driving through construction zones,
  - Ease of driver licensing,
  - Payment of fees and taxes,
  - Ability to bid projects and receive bid information timely and accurately, and
  - Streamlined procedures for contracting.

From this long list of congestion-related measures, there was no consensus among agencies as to what are the most important performance measures. However, performance measures that describe the number (quantity) of persons (or vehicles) served and the quality of travel were the most commonly reported.

#### **HOW LONG HAS YOUR AGENCY USED PERFORMANCE MEASURES?**

The study found that the age of performance measures programs varied greatly. Several agencies based the age of their performance measures' system on the age of traffic monitoring systems, such as HPMS, which can be 50 years old. Twenty-nine agencies reported the age of their programs; the average age was 14 years, the median and mode were both 10 years. This is consistent with the literature review, from which it was determined that a significant increase in published performance measures-related research occurred in the early 1990s. Some agencies are currently developing more comprehensive performance measures programs.

#### **WHAT MEASURES ARE USED IN OPERATIONS?**

Operators of limited access facilities—interstates, expressways, tollways, etc.—and operators of arterial road networks of all shapes and sizes have the need for some form of data and performance measures to support management functions. Basic core management functions are those functions that are generally applicable to all types of highways regardless of their classification or use, although the specific operational requirements, the associated information needs, the methods/technologies for collecting the information, and the level of deployment of data collection infrastructure may vary significantly.

##### **Traffic Control**

Traffic control often varies by roadway category. For arterials this may include traffic signal coordination, whereas for expressways this function may include ramp metering and interchange control. Other potential traffic control subfunctions include reversible lane control, variable speed limits, and integrated expressway—arterial control. Evacuation, special event, and military deployment routes usually have special traffic control needs. Performance measures that are commonly used for traffic control include

- Travel speeds,
- Travel time,
- Delay,
- Bandwidth,
- Queue length,
- Green time per cycle length,
- Cycles of delay per vehicle (the number of cycles a vehicle must wait prior to being given green time), and
- Throughput (passenger cars per hour).

##### **Incident Management**

Incident management includes both predicted and unexpected incidents, so that the impact on the transportation network and traveler safety is minimized. Activities include incident detection, verification, diagnosis, response (e.g., routing and tracking response vehicles), diversions, and clearance. Incidents include vehicular accidents, or crashes, in addition to other types of lane or roadway closures. Typical performance measures that are used in incident management systems include

- Crash rates;
- Crash type and location;
- Additional delay attributable to crashes;
- Average vehicle speeds and travel times (used to identify where crashes may have occurred);
- Cost of police traffic management operations;

- Emergency vehicle response times;
- Queue dispersion time;
- Incident detection, response, and clearance times; and
- Location and status response vehicles.

### Traveler Information

Traveler information functions include providing information to en-route motorists through roadside elements such as dynamic message signs and highway advisory radio transmitters. The information collected can also be used for information dissemination to travelers by other means (e.g., Information Service Providers, radios, and other in-vehicle devices). These applications include Advanced Traveler Information Systems (ATIS).

### System Coverage

Since 1999, ITS America and the U.S.DOT have focused on the data needs to support traveler information and the performance measures that are needed to support these needs. Those involved reviewed multiple market research reports and concluded that a survey of Washington State DOT traffic website users provides a reasonable representation of traveler information users in general. The following listing summarizes the relevant questions with the most frequent answers listed in order of popularity.

- Why use the website?
  - To assess traffic congestion on their route,
  - To judge the effects of incidents on their trip,
  - To decide among alternate routes,
  - To estimate their trip duration, and
  - To time their trip departure.
- What benefits are perceived from use?
  - Saved time,
  - Avoided congestion,
  - Reduced stress, and
  - Avoided unsafe conditions.
- What action results from the information?
  - Changed route or time of departure to maximize trip time.
  - Changed route or time of travel to reduce the stress of driving in congestion, perhaps lengthening trip distance or duration.
  - Adjusted expectations; listened to an audiotape book, made phone calls, changed appointments, and made alternative arrangements.

Based on these needs, ITS America identified specific data requirements to support traveler information. The following performance measures and data were determined to be the most needed in ATIS applications:

- Average travel speeds or times,
- Reports of abnormal events along their route,
- Images to view the route for themselves, and
- Route-specific weather conditions.

### Weather Management and Snow/Ice Management

Weather management includes detecting and forecasting weather—related hazards such as snowy/icy road conditions, dense fog, high winds, and approaching severe weather fronts. This knowledge can be used to more effectively deploy road maintenance resources. It can also be used in conjunction with other core functions such as traffic control (e.g., variable speed limits and signal coordination timings), incident management (e.g., routing response vehicles), and traveler information (e.g., general advisories and location-specific warnings).

Snow/ice management is applied to regions that experience snowfall and includes identifying the potential loss of vehicle traction, maneuverability and/or stability, the need for plowing (maintenance vehicle dispatch), lane(s) obstructions or other impairments to plowing, need for chemical application, low/loss of visibility, other impairments to vehicles/crews, short-term weather forecasting, and monitoring maintenance vehicles. Snow/ice management may be considered a specialty function of the overall weather management core function.

Performance measures associated with weather management and snow/ice management are used to describe air and road surface temperature, visibility, humidity and precipitation, wind speed and direction, road surface condition to characterize local climate, and roadway conditions.

Highway operators also often have the need to support additional management functions. Although not applicable to all operators, these functions are discussed here.

### Freight Management

Freight management is applied on freight routes and includes gathering vehicle classification information. It may also include automated clearance at roadside facilities, automated clearance at border crossings, ramp rollover warnings, downgrade warnings, monitoring vehicles carrying hazardous materials, and monitoring and warning over vehicle height. Performance measures to support freight management include vehicle length, height, and weight, and the number of axles that can be used to identify the individual characteristics of passing vehicles. Some motor carrier compliance offices on brake conditions also accumulate safety inspection statistics. Although not reported in the survey, some agencies report truck crashes as separate

from total accident rates. Commercial vehicle enforcement/inspection times and costs are also used.

### **Military Deployment Management**

Military deployment consists of traffic control and incident management functions situated along military deployment routes. Performance measures associated with military deployment management are similar to traffic and incident management performance measures with the addition of estimated time to arrive measures that predict a travel time along a desired route.

### **Special Event Management**

Special event management is the management of traffic during special events, whether a one-time event, an annual event, or recurring events such as sporting contests or school holidays. Performance measures associated with special event management are similar to traffic and incident management and include basic traveler information functions, but may also include performance measures related to clearance times (time for vehicles to clear an event center or the time required for evacuees to depart a dangerous area) and parking management measures (percent of spaces occupied and space turnover rate) for special event management.

### **Evacuation Management**

Emergency evacuation management is traffic control and incident management functions applied on evacuation routes. Performance measures associated with evacuation management include measures associated with traffic and incident management and traveler information functions, but may also include operational performance measures such as speeds, volumes, and delays.

### **Survey Results**

Most of the applications for performance measures identified through the research and the survey of state DOTs emphasized planning rather than operational uses. Many of the responding state DOTs reported very little formal development or long-term monitoring in operations. Only seven state DOTs (36% of the DOT respondents) reported the use of any performance measures in real-time. (MPOs are typically not involved in the operations of highway segments and systems and were not expected to provide operational performance measures.) Speed or travel time and incidents were the only measures that were reported used in real-time. The primary uses of these measures were in ITS operations centers or for providing data to travelers through ATIS. The performance measures reported to be used in operations included

- Travel time data for signal timing analysis,
- Safety measures to identify crash prone locations,
- Pavement and bridge conditions to prioritize maintenance activities,
- Construction project management, and
- ITS operations measures to support
  - Freeway traffic management,
  - Incident management, and
  - Traveler information systems.

An analysis of the results of the survey indicated that there are two possible explanations of the survey results: (1) that many measures are available and can be used to support operations, but few are actually put into practice or (2) that the survey respondents were directed to planning offices within their agencies and the use of performance measurement in operations is underreported.

State DOTs typically collect data for their entire state-maintained system either through the measurement of all components or through sampling. MPOs rely principally on state DOTs for their data collection, but the system they are concerned with is more expansive, considering all major public roads. Accordingly, MPOs typically reported a significantly lower percentage (30–50%) of coverage. These results are similar to the analysis of data system coverage reported in the literature.

### **WHAT OTHER MEASURES ARE BEING USED?**

Several other agencies reported agency performance measures that relate more to performance (outputs) of the agency than the outcomes (conditions experienced by the user). These measures include

- Performance-based budgeting,
- Number of guardrail blunt ends,
- Percent of railroad crossings actively protected,
- Weigh-in-motion,
- Video log images,
- Ability to achieve strategic objectives,
- Sufficiency index of geometric and pavement conditions, and
- Number of signals retimed per month.

### **WHAT OTHER USES FOR PERFORMANCE MEASURES WERE REPORTED?**

Although this synthesis emphasizes the use of performance measures for the operational effectiveness of highway segments and systems, many of the respondents reported alternate uses of performance measures for other than highways that included

- Transit,
- Bicycles,
- Pedestrians,
- Control of outdoor advertising,
- Justifying involvement of emergency services,
- Grant writing,
- Staff appraisals,
- Snow and ice operations performance, and
- Organizational performance index.

### **WHO ARE THE INTENDED AUDIENCES FOR THESE MEASURES?**

The agencies responding to the survey of state DOTs and MPOs and the literature review were very consistent in the intended audiences for performance measures. These audiences included decision makers within their agencies, partner organizations, and the public as follows:

- Governor's office,
- Legislature,
- Agency management,
- Agency staff,
- Elected officials,
- Other agencies
  - FHWA,
  - State DOTs,
  - MPOs, and
  - Municipalities,
- Public.

### **HOW ARE PERFORMANCE MEASURES REPORTED?**

The typical performance measures report occurs on an annual basis and is part of a transportation plan document. The measures are reported using a combination of written text (9%), tables (37%), charts (24%), and maps (24%). The report is typically made available on a website or published electronically on CD-ROM. The operational performance measures are used in ITS operations centers and may be disseminated using ATIS through a variety of media including television, radio, websites, and subscription-based services.

### **HOW ARE DATA COLLECTED IN SUPPORT OF THE PERFORMANCE MEASURES?**

A recent analysis of the Metropolitan ITS Deployment Tracking Database, a repository of deployment data for the 78 largest metropolitan areas in the United States, indicates that 70 of the 78 areas (90%) are gathering at least some type of traffic flow, incident, or transit vehicle location data. Figure 5 summarizes several key categories of data

collection by their total aggregated deployment in the 78 metropolitan areas as reported in 1997 and 1999 and projected in 2005. The analysis also indicates that only a handful of areas collect data over a large portion of their region. In 2000, for example, 39 metropolitan areas reported some sort of freeway surveillance, but only 9 areas reported covering greater than 50% of their total mileage. By 2005, 27 areas project that they will have 50% or more of their freeways under electronic surveillance.

No definitive information exists to characterize data collection deployment beyond these top 78 metropolitan areas; however, the consensus is that deployment is quite limited.

### **Data Collection Techniques**

The following section summarizes the major data collection techniques for gathering transportation system status data.

#### *Traffic Sensor Data*

Data of this type are speed, travel time, volume, vehicle classification, and occupancy or other numerical measurements used to characterize the flow of vehicles at a specific point or over a specific segment of a roadway. These data can be generated from many types of detection systems, such as loop detectors, microwave, infrared or sonic detectors, video image detection, automatic vehicle identification, license plate matching systems, and wireless phone probes. Volume, occupancy, classification, and speed data are typically collected at a point in the roadway (point data). Travel times are currently estimated based on "spot data" due to the costs of manually collecting these data historically. Ideally, these data will be collected over a section of a roadway using probe vehicles or other emerging technologies.

#### *Incident/Event Reports*

These data are characterized by descriptive information on planned or unplanned occurrences that affect or may affect traffic flow. Information on incidents such as construction/maintenance, events, road conditions, weather conditions, and crashes is also collected. These data are usually manually entered into a "system," although they can be stored and communicated either as text or through numeric codes. The manual entry into a system is the key differentiation from the traffic sensor data type. Recent advances in center-to-center interface standards will allow data communication between centers and the automatic saving of data in the databases. There are several types of road-related incidents/events, including

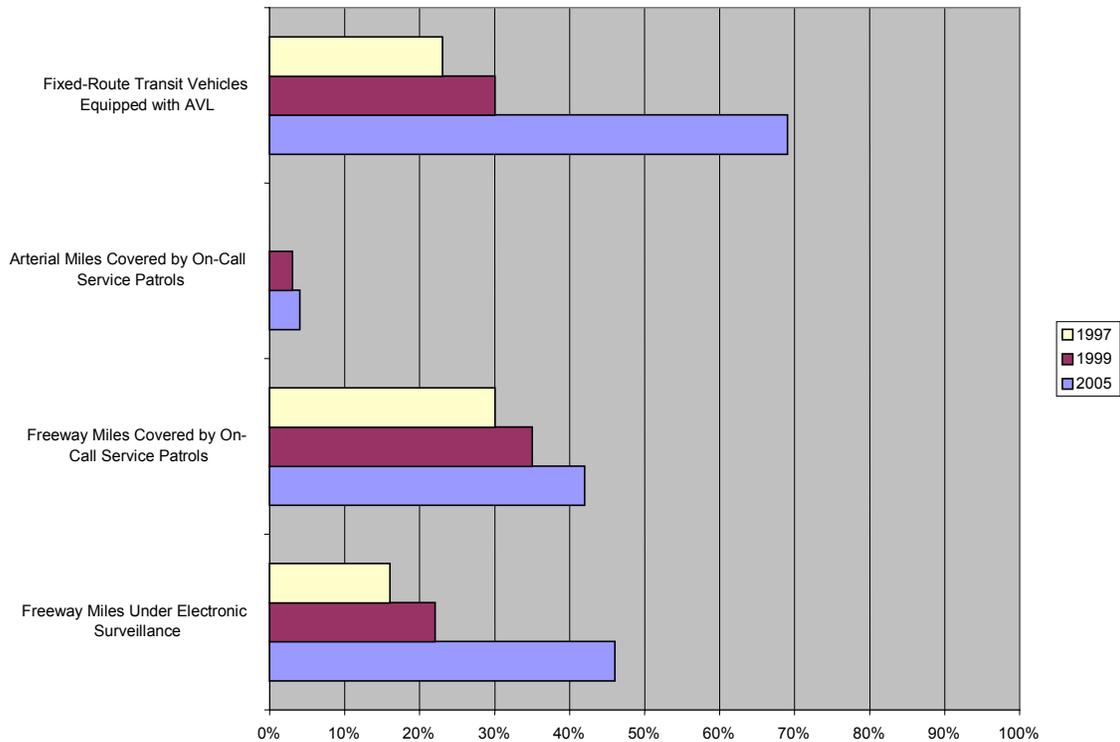


FIGURE 5 National summary of deployment (by percent deployment opportunity).

- Crashes, breakdowns, or other unplanned vehicle stoppages;
- Planned or emergency roadway construction or maintenance;
- Special events;
- General road conditions;
- General weather conditions;
- Traffic control device malfunctions; and
- Disasters.

There are currently no national standards or guidelines. Although police-investigated traffic accidents are usually reported in consistent formats from region to region, a national data definition effort is needed to record and analyze these data. Video images are commonly used to monitor the start and clearance time of incidents. Algorithms based on traffic characteristics collected using traffic sensor data can also be used to determine incident durations, but video is usually preferred.

#### Images

These data represent a snapshot of a roadway to give a visual depiction of current traffic conditions and are used primarily by operators. Images give a quick impression of traffic conditions that can be easily assessed by operators or travelers. However, this type of data is not

conducive to deriving detailed information, such as that which can be provided by traffic sensors. The data quality of images also varies from single images to broadcast quality video.

#### Road/Environmental Sensor Station Data

These data encompass a wide array of sensors including those that monitor weather, roadway, surface, and air/water quality conditions. These sensors can provide roadside data such as

- Elevation/atmospheric pressure;
- Wind data: direction, speed, gust direction, gust speed;
- Temperature: air, wet-bulb, dew-point, 24-h maximum, 24-h minimum;
- Humidity/precipitation: relative humidity, adjacent water depth, adjacent snow depth, roadway water depth, roadway snow and packed snow depth, precipitation indicator and type, precipitation rate, snowfall accumulation rate, ice deposit (thickness), precipitation start time, precipitation end time, total precipitation past  $X$  hours;
- Radiation: solar radiation, total sun, cloud cover situation;
- Visibility: surface visibility (measured in tenths of a meter), visibility situation (clear, fog, smoke, sea spray, blowing sand/dust, sun glare, insect swarms);

- Pavement sensing: pavement type, elevation, solar exposure, surface status (dry, moisture trace, wet, chemically wet, ice warning/watch, snow warning/watch, absorption, dew, frost), surface temperature, pavement temperature (2–10 cm below surface), surface water depth, surface salinity, surface conductivity, pavement freezing point, surface black ice signal, subsurface type, subsurface temperature, subsurface moisture;
- Pavement treatment: number of treatments, treatment type/mix (sand, dirt, gravel, cinders, water, salts, etc.), treatment form (dry, pre-wet, liquid), treatment amount (kilograms per lane-kilometer), treatment width; and
- Air quality: carbon monoxide, carbon dioxide, nitrous oxide, nitrous dioxide, sulfur dioxide, ozone, particulate matter.

#### *Other Data Collection Techniques*

Other data collection techniques identified by respondents included

- Accelerometers (profilometer) for road surface condition, bridge inspection, and pavement condition;
- Accident reports;
- Aerial photo surveys;
- Census data for population and employment;
- Floating car studies;
- Roadway characteristics inventories—for basic geometric and traffic control information;
- Railroad crossing inventory;
- Project-specific information;
- Customer survey;
- Modeling/estimation; and
- Travel survey.

Table 9 summarizes the results of the survey and includes other known professionally accepted data collection techniques.

Data collection occurs over a wide range of frequencies. This is a function of the requirements for data reporting and helps determine whether data will be used for planning applications or operations. Data to be used in the support of planning applications are typically collected once per year or sampled once every 3 years and used to estimate annual conditions. Several agencies reported quarterly data collection; however, these were for smaller systems. Volume, counts, and speed information are collected using roadside equipment such as inductive loops or microwave radar traffic monitoring systems. Travel time studies using floating car methods or travel surveys are performed less frequently; that is, every 5 or 10 years or when there is a specific project need.

Operational-related data are principally derived from ITS systems, and the frequency of data reporting ranges from 5 s to 5 min.

Typically, state DOTs are fully responsible for the standards and requirements for data collection and data collection activities to support performance measures. In some cases, the state DOT partners with one or more local agencies to provide some of the data. These data collection activities may be performed by agency staff or by consultants who use agency standards and criteria. Validation of local agency data may be performed by the state DOTs, with the exception being safety data, which are typically provided by law enforcement agencies and compiled and analyzed by the state DOTs.

#### *Costs of Data Collection Systems in Support of Performance Measures*

To reduce costs most data collection systems for performance measures rely on traditional data and reporting systems such as the HPMS. Where additional data collection is needed to support measures that cannot be derived from the other data sources, new data collection systems are required. However, the costs are typically integrated in congestion management or monitoring systems to cover all activities. Several agencies provided estimates of the costs of their data collection programs to support performance measures. The data provided were expressed in full-time equivalents or actual dollars. These data were converted to dollars based on an equivalent cost (including overhead and benefits) of \$100,000 per annual full-time equivalent for office staff and \$50,000 per year for field staff (Table 10).

For many agencies, funding to support this data collection has evolved over time as a part of the transportation planning process. Agencies with active programs identified funding to support the data collection as part of the institutional change that led to their implementation. Several agencies reported allocation of the funding through their business planning process, quality initiative, or in response to legislative mandates.

The typical funding programs used included federal and state programs. Federal PL (planning) funds, planning and research funds, and surface transportation programs were the most commonly cited sources of the funding. Several agencies reported using internal operational funds to support their programs.

#### **HOW ARE THE DATA STORED AND WHO IS RESPONSIBLE FOR THE DATA?**

Data are typically stored in a mainframe or personal computer database. Several agencies reported that no single

TABLE 9  
DATA COLLECTION TECHNIQUES AND TYPE OF DATA PROVIDED

Technique/Technology	Data Element
Customer surveys	Customer satisfaction Incident response times Satisfaction with maintenance/construction zones Satisfaction with traveler information Satisfaction with HOV lanes Satisfaction with ramp meters Satisfaction with service patrols
Travel surveys	Origin–destination Number of daily trips and purpose Trip-based travel time Travel predictability Congestion tolerance
Inductive loops	Traffic volumes and classification Density (indirectly through vehicle occupancy) Speed Lane occupancy
Other nonintrusive vehicle detectors <sup>1</sup>	Traffic volumes and classification Density Speed Lane occupancy
Video surveillance <sup>2</sup>	Incident detection
Probe vehicles <sup>3</sup>	Travel times Speeds
Modeling/estimation <sup>4</sup>	Capacity LOS VMT Evacuation clearance time Percent system congested Percent travel congested Duration of congestion Travel times Speed Benefits Queuing Delay V/C ratio

Note: This table does not include all of the data collection techniques reported, but only the results that were reported most often. HOV = high-occupancy vehicle; VMT = vehicle-miles traveled; LOS = level of service; V/C = volume/capacity.

<sup>1</sup>Includes hoses/tubes, radar, acoustic, video, and seismic technologies.

<sup>2</sup>Does not include video detection: surveillance use only.

<sup>3</sup>Using transponders, license plate surveys, and global positioning systems (GPS).

<sup>4</sup>For existing and forecasted data using travel demand models, unique models, or simulation models.

TABLE 10  
COSTS OF DATA COLLECTION PROGRAMS

Statistic	MPOs	DOTs
Mean	\$278,000	\$5,966,667
Median	\$200,000	\$2,500,000
Mode	\$200,000	
Minimum	\$5,000	\$200,000
Maximum	\$1,200,000	\$25,000,000
Count	12	9

Notes: MPOs = metropolitan planning organizations; DOTs = departments of transportation.

person or office was responsible for the storage of data, but rather a distributed approach was used for the storage and responsibility of data. Several agencies did report a centralized approach within their traffic monitoring office. Typical data storage was for 5 to 10 years. However, other agencies reported that data were stored for an indefinite period.

## ROLE OF INTELLIGENT TRANSPORTATION SYSTEMS IN OPERATIONAL PERFORMANCE MEASURES

ITS are the application of communication and information technology to traffic and incident management. The use of information collected using ITS technologies is the primary operational environment where performance measures are most likely to be employed. ITS technologies and strategies also provide the greatest opportunity to share resources in the collection of data needed to support mobility performance measures. To understand the potential for partnerships within this area, a review of the use of performance measures associated with ITS was performed. This review consisted of a study of national and statewide documents and the reporting of performance measures associated with ITS, and a survey of practitioners to determine the state of the practice of performance measurement in ITS.

### Federal ITS Performance Measures

The Joint Program Office of the U.S.DOT is very active in the testing and evaluation of a number of performance measures. The primary measures recommended at a national level are used in the program review of major metropolitan ITS systems and benefits evaluation of system deployment. The measures employed in these analyses include

- Safety
  - Reduction in crash rates—Total, fatalities, and injury.
- Mobility
  - Reduction in travel time delay,
  - Reduction in travel time variability, and
  - Improvement in customer satisfaction.
- Efficiency
  - Increased throughput,
  - Productivity, and
  - Reduced travel costs.
- Energy and environment
  - Reduced emissions, and
  - Reduced energy consumption.

Each of these measures has been deployed and tested in major metropolitan ITS systems. National statistics have been extrapolated for many of the measures to summarize the estimated benefits of ITS.

### Performance Measures Used in ITS Operations

As part of Florida’s ITS strategic plan (PB Farradyne 1998) a survey was conducted involving 23 state DOTs and ITS operating agencies throughout the United States. Fifteen of the 26 agencies contacted provided either a written response to the survey form or forwarded relevant documents. These respondents are listed here.

- Gary–Chicago–Milwaukee Priority Corridor,
- Colorado DOT,
- I-95 Priority Corridor,
- Washington State DOT,
- Virginia DOT,
- Wisconsin DOT,
- Houston Priority Corridor,
- Minnesota DOT,
- Missouri DOT,
- California DOT,
- Maryland State Highway Administration Coordinated Highways Advisory Response Team (CHART),
- New Jersey DOT,
- Texas DOT, and
- Utah DOT.

At the time of the survey, 8 of the 11 agencies that responded to this question were not monitoring the performance of ITS equipment. Three agencies (Washington, Houston,

and California) were conducting performance monitoring. Washington uses loops to determine speed and travel time, Houston uses toll tag readers to monitor speed, and California conducts studies at specific locations using different equipment and methods. The Florida DOT does not have a formal process for monitoring ITS performance, but some districts collect performance data on many individual ITS projects and use these data in operations management.

Performance measures used in operational management of highway systems and segments are usually associated with ITS and include delay and incidents. Observations of delays and incidents in real time in the highway environment result in the deployment of incident response teams, deployment of traveler information through roadside information signs, and other ATIS. Information on delays and travel times are used to influence traveler route and timing decisions.

### DIFFERENCES BETWEEN RURAL AND URBAN SYSTEMS

The performance measures identified in the research literature and transportation agency applications were oriented toward urban highway segments and systems, but are not exclusively urbanized in nature. Many of the performance measures identified and discussed in this synthesis are applicable to both urban and rural applications.

However, the data requirements and reporting of these measures may be quite different because the audiences are different. Users interested in urban data tend to be commuters familiar with roadway networks and systems and who in an operational setting are more willing to make travel behavior or route changes. Commercial intercity travelers may be sensitive to small changes in travel times and speeds and be willing to alter their travel behavior or change their route. However, passenger intercity travelers tend to be less sensitive to small changes in travel times or speeds and are less willing to alter travel behavior or change route, particularly if it is for a nonwork-related purpose. In urban applications, estimating travel times using “spot speeds” is generally considered reliable for extrapolating trip travel times along corridors; however, in rural segments of any significant length (greater than 20 mi) probe data techniques are needed to reliably estimate travel times.

### HIGHLIGHTS OF FEDERAL, STATE, AND LOCAL AGENCY PRACTICES

This section summarizes some of the federal, state, and local agency practices in the areas of performance measures for the operational effectiveness of highway segments and systems.

## Federal Highway Administration

This annual *Performance Plan and Performance Report* documents the overriding mission, vision, goals, objectives, and measures of the FHWA. Within this plan, performance measures are tied to specific strategic goals and benchmarks are established for desired outcomes. The report includes trend charts and tables and specific strategies that will be employed to achieve the target benchmarks. The following list summarizes the measures used.

- Safety
  - Fatalities per 100 million VMT,
  - Number of highway-related fatalities,
  - Highway-related injuries per 100 million VMT,
  - Number of highway-related injuries (millions),
  - Accidents per 100 million VMT, and
  - Number of accidents.
- Mobility
  - Percentage of VMT on National Highway System (NHS) pavements with acceptable ride quality ( $IRI \leq 170$  in./mile;  $IRI$  = international roughness index);
  - Percentage of bridge deck area classified as deficient for all average daily traffic (structurally deficient or functionally obsolete), reported for NHS and other bridges;
  - Percentage of those satisfied with the nation's highway systems;
  - Percentage of travel under congested conditions;
  - Percentage of additional travel time caused by congestion;
  - Annual hours of delay;
  - Increase in system reliability (to be defined); and
  - User satisfaction with operations of the highway system (to be defined).
- Productivity
  - Growth in congested travel,
  - Growth in congested delay,
  - Cost of highway freight per ton-mile (to be determined),
  - Hours of delay at border crossings (to be determined),
  - Travel time of key freight corridors (to be determined), and
  - Use of engineering/economic analysis tools for assisting benefits.
- Human and natural environment
  - Level of community satisfaction,
  - On-road mobile source emissions in short-tons, and
  - Wetland replacements in acres.
- National security
  - Percentage of miles on the Strategic Highway Network (STRAHNET) for defense mobility with  $IRI \leq 170$  in./mile,

- Percentage of STRAHNET bridges rated deficient, and
- Percentage of STRAHNET routes under bridges with clearance greater than 16 ft.
- Organizational excellence
  - Customer/partner rating of the timeliness of decision making, usefulness of information, and competency of personnel;
  - Employee job satisfaction;
  - Percentage of payroll for training and development;
  - Percentage of obligations expended; and
  - Number of months to process documents required by the National Environmental Policy Act.

The mobility measures that are applicable to the operational effectiveness of highway systems and segments were derived from the FHWA's HPMS.

## Intelligent Transportation Infrastructure Program

The U.S.DOT's Intelligent Transportation Infrastructure Program (ITIP), which was established in the Transportation Equity Act for the 21st Century (TEA-21), was a first attempt to document a core set of performance measures and data collection standards for use in operations and planning. Under this program, a preselected private partner will deploy a system in the selected area(s) that will result in the ability to measure the operating performance of the roadway system at a regional and national level. Specifically, the primary objectives of the program are

- To accelerate the integration and enhancement of intelligent transportation infrastructure in major metropolitan areas to enable and help manage the continuous monitoring of the roadway system for purposes of providing real-time as well as archived data to aid in the operation, planning, analysis, and maintenance activities of the U.S.DOT and state and local agencies;
- To enhance the quality, availability, and accessibility of transportation system performance data to enable the calculation of mobility performance and system reliability measures while at the same time satisfying system operational needs;
- To provide performance data and reports to the U.S.DOT;
- To provide a traveler information service that includes free public access to basic traveler information and supports the provision of a 511-based telephone service;
- To realize and publicize the benefits of regionally integrated and interoperable intelligent transportation infrastructure capable of supporting regional as well as national needs; and
- To provide private technology commercialization initiatives to generate revenues that will be shared with the transportation agencies.

TABLE 11  
INTELLIGENT TRANSPORTATION INFRASTRUCTURE PROGRAM PERFORMANCE MEASURES

Performance Measures	Description
Annual person-hours of delay	= daily vehicle hours of delay x 250 working days per year x 1.25 persons per vehicle
Percent congested travel	= (VMT under congested conditions)/(total VMT for the area)
Travel rate index	= (travel time under congested conditions)/(travel time under uncongested conditions)
Travel time percent variation	= [(standard deviation)/(average travel time)] x 100%
Travel time buffer index	= $\frac{95\% \text{ confidence travel rate} - \text{average travel rate}}{\text{average travel rate (in minutes per mile)}} \times 100\%$
Travel time misery index	= (average of the travel rates for the longest 20% of the trips) – (average travel rates for all trips)

Notes: VMT = vehicle-miles traveled.

The ITIP is designed to use and enhance existing surveillance infrastructure, while also allowing for the deployment of supplemental surveillance infrastructure. The proposed system must accommodate

- Creation of a process and mechanism to collect, integrate, archive, manage, and report new and existing transportation data for mobility and performance monitoring, planning, evaluation, and other similar purposes;
- Creation of a data repository for new and existing real-time traveler information for dissemination to the traveling public through a variety of delivery mechanisms, including support for a 511-based telephone service, provision of free basic traveler information to the public, and commercial traveler information services;
- Creation of a regional transportation information system that integrates and supplements existing surveillance infrastructure to support public sector transportation management needs and private sector commercialization;
- Accommodation/integration of existing transportation data collection, archiving, and dissemination mechanisms; and
- Collection of data primarily through wireless transmission along with some shared wide-area networks.

Additionally, the system must be operational within 1 year of the date of award.

The U.S.DOT will make \$2 million available to each selected area through the Intelligent Transportation Omnibus Procurement contract vehicle. A 20% matching share totaling \$500,000 must be provided in cash from nonfederally derived funding sources (either state, local government, or other private sector partners). Mobility Technologies, the selected contractor, will also contribute \$500,000 in private funds to this project.

A set of national performance measures was designated and is supported by standards for data collection under this program. Tables 11 and 12 summarize these measures and the data standards.

**California Department of Transportation**

Performance measures should relate to outcomes describing cause-and-effect relationships that involve owners/operators and users. Outcome measures relate to the experience of the user and describe the quality of service provided during transport, such as speeds or travel times. Output measures are indicators of the direct production of an organization, such as lane-miles constructed. Because transportation system performance is influenced by many factors that transportation agencies cannot control, such as the weather, economic cycles, and land-use patterns, organizational management often favors output measures. Output measures are favored because they reflect actions the agency can take to improve highway performance; however, for them to be useful, they must also be considered in conjunction with outcome measures that describe the conditions experienced by the user.

The California DOT developed a framework for performance measures/indicators based on the following criteria relating to outcomes:

- The use of existing data sources to confirm existing activities in California’s regional transportation planning organizations, wherever possible;
- The measures/indicators must be easy to use and simple to understand; and
- The measures/indicators should be measurable across all modes to the greatest extent possible.

The California DOT uses performance measures to

- Monitor and evaluate system performance,
- Share existing data and future forecast performance information,
- Develop modal-neutral customer and decision information,
- Build consensus on investment decisions, and
- Improve accountability of system development and operations.

Figure 6 illustrates the basic framework of the California DOT’s performance measures program. The candidate

TABLE 12  
INTELLIGENT TRANSPORTATION INFRASTRUCTURE PROGRAM DATA SPECIFICATIONS FOR MOBILITY  
MONITORING

Primary Data Element	Attributes		Supplemental Data Elements
	Preferred	Acceptable	
Vehicle travel times (preferred)	For individual vehicles For defined roadway links up to 1 mi in length Coverage on freeways and arterial streets	5- to 15-min summary average For defined roadway links 1–3 mi in length Coverage on freeways only	Date of measurement Start time of travel time Anonymous vehicle identification
Vehicle spot speeds (acceptable)	1- to 5-min averages by lane Speeds obtained every 2 mi Coverage on freeways and arterial streets	1- to 5-min averages by direction Speeds obtained every 1–3 mi Coverage on freeways only	Date of measurement Start and end time for speed summary statistics Detector location identification (milepost or other location reference)
Vehicle volumes	1- to 5-min totals by lane Volumes obtained every 2 mi Coverage on freeways and arterial streets	1- to 5-min totals by direction Volumes obtained every 1–3 mi Coverage on freeways only	Date of measurement Start and end time for volume summary statistics Detector location identification (milepost or other location reference)
Roadway link and “corridor” identification	Definition of roadway links up to 1 mi in length	Definition of roadway links of 1–3 mi in length	Corresponding detector identification Milepost or location reference Roadway name and direction Sequence of link along a corridor Link length Number of lanes
Vehicle classification	The 13 vehicle classes defined in the Traffic Monitoring Guide ( <a href="http://www.fhwa.dot.gov/ohim/tmguide/index.htm">http://www.fhwa.dot.gov/ohim/tmguide/index.htm</a> )	Passenger vehicles (cars and light pick-ups) Single-unit trucks Combination trucks (tractor trailers)	Date of measurement Start and end time for volume summary statistics Detector location identification (milepost or other location reference)

performance measures/indicators incorporated into the framework are summarized in Table 13.

Key highway/operational performance measures in the California DOT program include mobility and reliability. Average delay per vehicle is used as a mobility performance measure and is derived from the difference between free-flow travel times, based on posted speeds, and the estimated travel times, based on measured or modeled speed estimates during the analysis period. Reliability is defined as the variability in transportation services between the expected and actual travel time. The percent variation, standard deviation of travel times divided by the average travel time, is used to estimate this variability. Application of this reliability measure in the cities of San Francisco and Los Angeles, and Orange and San Diego counties indicates that this variability measure may not be correlated with delays and that it depends on a number of factors, including the distance between interchanges, roadway geometries, and other factors.

In addition to the system performance measures identified as part of the transportation planning, operational

performance measures were derived to serve the following purposes:

- To develop indicators/measures to assess the performance of California’s multimodal transportation system to support informed transportation decisions by public officials, operators, service providers, and system users (talk about integration); and
- To establish a coordinated and cooperative process for consistent performance measurements throughout California (real integration).

Figure 7 shows the linkage of desired system performance outcomes that were identified through a public process. These outcomes are estimated by performance indicators and calculated using outputs from transportation agencies. Such measures are intended to support decision making at all levels in the department and address systems and corridors rather than piecemeal project benefits. Figure 8 illustrates this approach. As can be seen in the figure, monitoring and evaluation serves as the basis for making decisions on improvements to the transportation system.

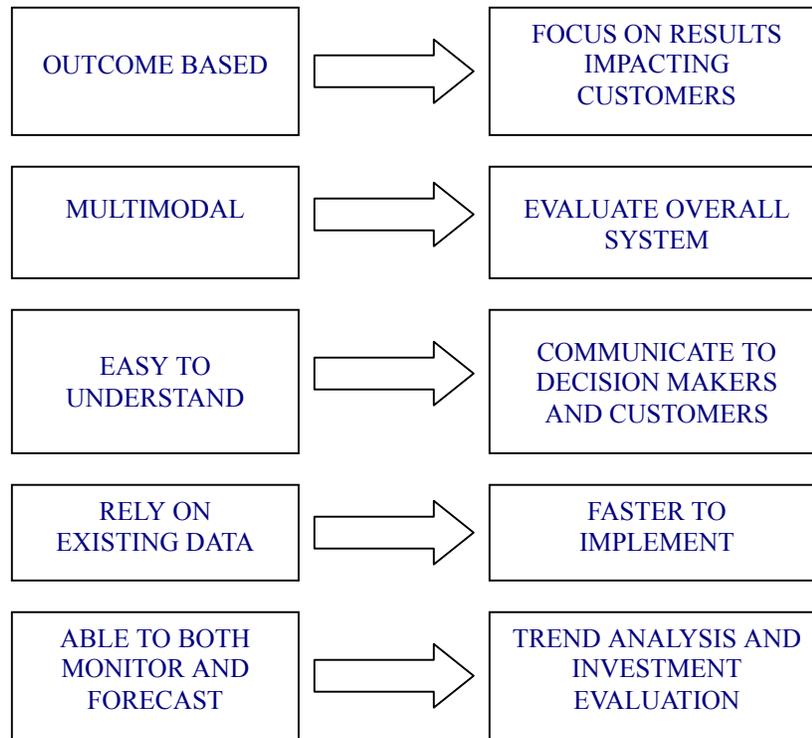


FIGURE 6 California DOT's performance measures framework.

TABLE 13 CALIFORNIA DOT'S PERFORMANCE MEASURES/INDICATORS

Desired Outcome	Definition	Candidate Measure/Indicator
Mobility/accessibility	Reaching a desired destination with relative ease within a reasonable time, at a reasonable cost with reasonable choices	Travel time Delay Access to desired location Access to system
Reliability	Providing reasonable and dependable LOS by mode	Variability of travel time
Cost-effectiveness	Maximizing the current and future benefits from public and private transportation investments	Benefit/cost ratio
Sustainability	Preserving the transportation system while meeting the needs of the present without compromising the ability of future generations to meet their own needs	Outcome benefit per unit cost
Environmental quality	Helping to maintain and enhance the quality of the natural, physical, and human environment	Household transportation costs
Safety and security	Minimizing the risk of death, injury, or property loss	Accident and crime rates
Equity	Distributing benefits and burdens fairly	Benefits per income group
Customer satisfaction	Providing transportation choices that are safe, convenient, affordable, comfortable, and meet customers' needs	Customer survey
Economic well-being	Contributing to California's economic growth	Final demand (value of transportation to the economy)

Notes: LOS = level of service.

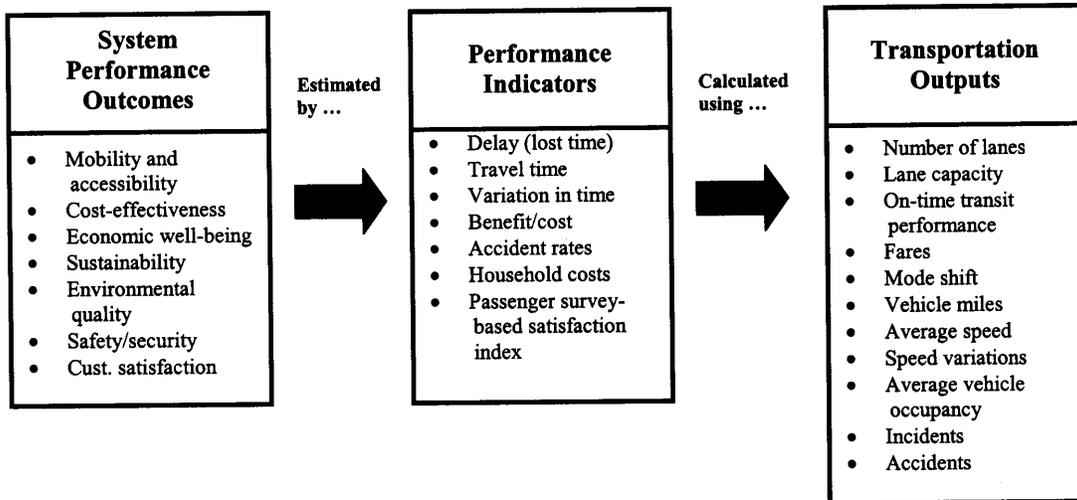


FIGURE 7 California performance measures.

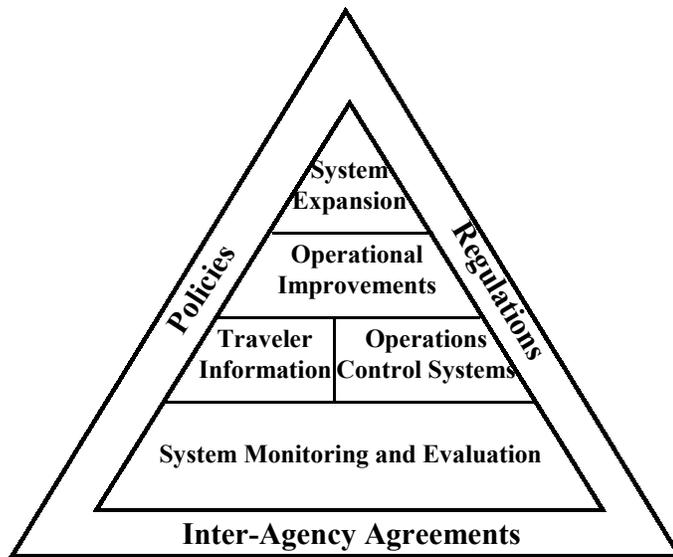


FIGURE 8 California DOT's operations-oriented decision approach.

**Delaware Department of Transportation**

Only if mobility performance measures are consistent with established goals and objectives for transportation and related systems can they be used to influence the processes and achieve the desired results.

The Delaware DOT addresses performance measures in its Statewide Long-Range Transportation Plan, *Transportation and Delaware's Future* (2000). Performance measures were derived from the goals and objectives of the plan. Table 14 summarizes these measures and their link to the goals, strategies, and policies of the plan.

**Florida Department of Transportation**

The Florida DOT developed a framework for performance measurement designed to characterize mobility in a manner understandable to the general public and decision makers. The recommended mobility performance measures reflect mobility from the users' perspectives, based on the following:

Mobility is defined as the ability to satisfy the demand to move a person or goods and can be described by four parameters:

- The quantity of the travel (number of persons served),

TABLE 14  
COMPONENTS AND MEASURES OF THE DELAWARE STATEWIDE LONG-RANGE TRANSPORTATION PLAN

Plan Components	Definitions	Measure Types	Measures
Goals	Broad desired end-states	Outcome performance measures with identified analytical tools	Customer satisfaction Travel time Sustainability of investments
Strategies	General approaches with objectives that advance the achievement of goals	Outcome performance measures answered with yes/no responses supported by indicators of progress	Support for existing communities Increased system capacity Increased safety Improvement and protection of air quality, environment, and cultural resources
Policies	Implementation schemes through specific action initiatives or policy-driven approaches to routine processes	Output performance measures at the most discrete level expressed as indicators of performance	Decrease in average trip length Decrease in the rate of VMT growth Increase in new revenue sources Decrease in mode share for single-occupant vehicle travel
Actions	Specific initiatives including procedural changes and capital improvement projects	Output performance measures including policy indicators and measures developed as part of specific project implementations	Increase in the tonnage of goods moved Increase in ridesharing Decrease in crash rate Increase in work zone safety

Notes: VMT = vehicle-miles traveled.

- The quality of travel (travelers’ satisfaction with travel),
- The accessibility of travel (ability to reach the destination and mode choice), and
- The utilization of a facility or service (the quantity of operations with respect to capacity).

Three basic types of applications were identified for the mobility performance measures.

- Functional systems—These applications address the combination of similar facilities that serve the same function (e.g., interstates serve intercity travel).
- Areawide systems—These applications address the analysis of a combination of facilities and services that are defined by geographical boundaries.
- Corridors—These applications address the analysis of multimodal transportation services between a specific origin and destination. Corridor analyses usually consist of the analysis of one or more facilities and services that provide direct access between an origin and destination.

Table 15 summarizes Florida’s mobility performance measures for these dimensions and applications.

**Maryland State Highway Administration**

The Maryland State Highway Administration (MDSHA) has derived and publishes an annual *Highway Indicators Statistical Report* that provides a graphically oriented summary of performance trends. The performance measures identified are classified as follows:

- System extent
  - Centerline-miles,
  - Lane-miles,
  - Lane-miles by functional class,
  - Bridges,
  - Linear feet of sidewalk on state highways,
  - Noise barriers,
  - Signalized intersections,
  - Modern roundabouts,
  - Modern roundabout listing,
  - Park-and-ride facilities served by transit,
  - Park-and-ride facilities by number of spaces,
  - Park-and-ride facilities’ listing,
  - NHS, and
  - Welcome centers and rest areas.
- System use
  - Annual VMT,
  - Annual VMT on state highways,
  - Annual VMT by region,
  - Annual VMT per licensed driver,
  - Historic use of state-operated rideshare facilities,
  - Traffic fatalities,
  - HOV lane use on I-270, and
  - Truck average annual daily traffic at selected locations.
- Capital invested
  - Annual MDSHA expenditures,
  - Funding distribution, and
  - Expenditures for community enhancements.
- Factors influencing system design
  - Population, labor force, and households;
  - Highway indicators (lane-miles, annual VMT, population, licensed drivers, registered vehicles, and labor force);

TABLE 15  
FLORIDA DOT MOBILITY PERFORMANCE MEASURES AND DATA SOURCES

Mobility Performance Measures	Data Requirements	Source
Quantity of Travel		
Person-miles traveled	Average annual daily traffic (AADT) Hourly k	Roadway characteristics inventory (RCI) Estimated from telemetered traffic monitoring sites (TTMS) system raw data files grouped by LOS facility types
	Hourly volume Length Vehicle occupancy	Hourly k $\times$ AADT RCI 1990 National Personal Transportation Survey county-wide average journey to work data
Truck-miles traveled	AADT Hourly volume Length Percent trucks daily Percent trucks peak hour	RCI Hourly k $\times$ AADT RCI RCI Estimated TTMS system raw data files grouped by LOS facility types
Vehicle-miles traveled	AADT Hourly volume Length	RCI Hourly k $\times$ AADT RCI
Person-trips	Total person-trips	Florida Standard (travel demand forecasting) Model output files
Quality of Travel		
Average speed	Average segment speed	Estimated using planning applications from 1994 Highway Capacity Manual adapted for Florida and extended for saturated conditions
Delay	Person-miles traveled Average segment speed Free-flow speed	See above See above Estimated using posted speed limits in RCI
Average travel time	Distance Speed	RCI See above
Average trip time	Door to door trip travel time	Florida Standard (travel demand forecasting) Model output files
Reliability	Median travel times Travel time distribution	Six-week field studies Six-week field studies
Maneuverability	Hourly volume Length	Hourly k $\times$ AADT RCI
Accessibility		
Connectivity to intermodal facilities	Intermodal facilities of significance Intermodal connectors	Public Transportation Office Public Transportation Office
Dwelling unit proximity	System location Dwelling units	State highway system base map Statewide transportation planning package from the 1990 Census
Employment proximity	System location Employment location	State highway system base map Statewide transportation planning package from the 1990 Census
Industrial/warehouse facility proximity	System location Industrial warehouse facility location	State highway system base map Statewide transportation planning package from the 1990 Census
Percent-miles bicycle accommodations	Miles of roadway with bicycle accommodations Total system miles	Florida DOT bicycle coordinator RCI
Percent-miles pedestrian accommodations	Miles of roadway with pedestrian accommodations Total system miles	Florida DOT bicycle coordinator RCI
Utilization		
Percent system heavily congested	Hourly volume Segments operating at LOS E or F Segment length System miles	Hourly k $\times$ AADT Use of generalized LOS tables RCI RCI
Percent travel heavily congested	Hour volume Segments operating at LOS E or F Segment volume $\times$ length System VMT	Hourly k $\times$ AADT Use of generalized LOS tables See above See above
Vehicles per lane-mile	AADT Length Lane-miles	RCI RCI RCI
Duration of congestion	Hourly volume Hours of the day that segments operate at LOS E or F Lane-miles	Hourly k $\times$ AADT Use of generalized LOS tables RCI (lanes) $\times$ RCI (length)

Notes: k = the ratio of volume in the analysis hour to AADT; VMT = vehicle-miles traveled.

- Labor force and annual VMT;
- Motor vehicle registrations; and
- Licensed drivers, driving age population, and motor vehicles.
- System conditions
  - Number of congested intersections,
  - Percentage of congested intersections,
  - Number of deficient bridges,
  - Percentage of deficient bridges,
  - Pavement condition,
  - Congestion,
  - Travel rate index,
  - Hours of total delay,
  - Number of incidents that result in hours of total delay,
  - Percentage of lane-miles operating at LOS E or F, and
  - Express bus travel time.
- Community enhancements
  - Noise barriers, locations, and miles needed;
  - Sidewalk location and miles needed;
  - Bike trails and miles funded;
  - Streetscapes/neighborhood conservation, number of projects, and funding;
  - Wetlands reforestation, total and net acres created; and
  - Percent of emissions from mobile sources.

In addition to this annual report, the MDSHA published a *Four-Year Business Plan: 2000–2004* (2000) that identified the following additional mobility performance measures:

- Reduction in average incident response time,
- Reduction in average clearance time,
- Number of cumulative CHART/ITS devices installed,
- Number of regional traffic operations centers integrated with CHART,
- Number of website enhancements,
- Percentage increase in website hits,
- Percentage of cameras that are media accessible,
- Number of projects that are intended to enhance intermodal connections,
- Number of users of MDSHA park-and-ride lots,
- Percentage of centerline-miles along urban state roads within 0.6 mi of a transit station that has sidewalks,
- Complete website linkage,
- Projects that reduce recurring congestion,
- Intersection capacity projects where the V/C ratio has improved 1.0 or better,
- Reduction in fatal and injury accident rates,
- Reduction in number of pedestrian fatalities and injuries,
- Reduction in number of bicycle fatalities and injuries, and
- Reduction in motor carrier fatalities and injuries.

### Minnesota Department of Transportation

These diverse sets of measures have evolved over time from a core set of performance measures that addressed system performance, organizational performance, and public values. The proliferation of measures resulted from a desire to tie measures to support budgeting principles of each specific goal and objective of their transportation plan, integrate and align planning and investment decisions through performance-based planning, reflect externalities out of their control, assist in making trade-off decisions, establish a hierarchy of measures throughout the department, and provide measures that resonate with customers and help explain the progress.

The Minnesota DOT (MnDOT) system performance measures include

- Pavement quality and estimated remaining service life,
- Deficient bridges and square feet of deficiencies (measured in square feet of area),
- Crash rates,
- High accident locations (intersections and rail crossings),
- Miles and hours congested,
- Mobility, and
- Reliability.

Of particular interest and importance is MnDOT's emphasis on freight and intermodal performance measures. These measures were established based on the results of a task force that included public and industry representatives. The task force emphasized the basic concepts that were important to them for the Twin Cities (Minneapolis and St. Paul) metropolitan area and statewide application, and MnDOT staff defined corresponding measures. Table 16 shows the performance measures proposed.

In a presentation, *Performance Measurement Directions and Issues* (2000), Larson identified current trends and issues in the MnDOT performance measure program. This presentation emphasized the integration of performance measures into the business planning process of the MnDOT and the family of measures used to support MnDOT's business plans. However, the presentation identified the following key customer needs that are important for highway performance measures:

- Time predictable trips;
- Smooth, uninterrupted trips;
- Safe trips;
- Timely and accurate information; and
- Responsibility with resources.

This presentation also identified market segmentation needs for performance measures as follows:

- Commuters,

TABLE 16  
FREIGHT-ORIENTED PERFORMANCE MEASURES FROM MINNESOTA

Performance Concept	Performance Measures
Predictable, competitive Twin Cities' travel time	<ul style="list-style-type: none"> <li>• Metro freeway travel time by route and time of day</li> <li>• Average speed on metro freeways by route and time of day</li> <li>• Congestion ranking of metro freeways, by route</li> <li>• Congestion level compared with other major metro areas</li> </ul>
Economic benefit/cost	<ul style="list-style-type: none"> <li>• Benefit/cost ratio of major state transportation projects</li> </ul>
Transportation investment	<ul style="list-style-type: none"> <li>• State's transportation investment and spending as percent of gross state product</li> </ul>
Intercity travel time	<ul style="list-style-type: none"> <li>• Peak-hour average travel speeds on major routes between 27 state regional centers</li> <li>• Shipper point-to-point travel time</li> </ul>
Freight travel time to global markets	<ul style="list-style-type: none"> <li>• Travel time to major regional, national, and global markets—by rail, air, water, and truck</li> </ul>
Competitiveness of shipping rates	<ul style="list-style-type: none"> <li>• Shipment cost per mile—by ton or value, by mode for major commodities</li> </ul>
Crash rate and cost comparison	<ul style="list-style-type: none"> <li>• Dollar value of crashes and crash cost comparison by mode</li> <li>• Crash rate per mile traveled by freight mode</li> </ul>
Bottlenecks and impediments	<ul style="list-style-type: none"> <li>• Number of design impediments to freight traffic, by mode, by type</li> </ul>
Timely access to intermodal terminals	<ul style="list-style-type: none"> <li>• Number of design impediments slowing access to truck, rail, air, and waterways terminals</li> </ul>

- Personal travelers,
- Farmers,
- Emergency vehicle operations,
- Carriers,
- Shippers, and
- Intermodal.

In addition, Larson's presentation identified data management needs as follows:

- Standard methods for collecting data are needed, particularly for speed and travel times.
- Data and methodologies are needed to support system integration and linkages.
- Data currency (timeliness) is of particular concern. Users seek accurate data in near real-time for many applications and this demand for real-time traffic data makes quality control a challenge.

**Texas Department of Transportation**

The Texas DOT uses a balanced scorecard approach to developing performance measures (Figure 9). Measures have been designated to ensure that all four quadrants of the matrix that reflects focus (external vs. internal) and product (process or result) are addressed.

The measures are derived from goals and objectives provided in the agency's strategic plan. One hundred and one measures are identified and maintained in a database. This database includes the traceability to the goals and objectives, definitions, data limitations, data sources, computation methods, and purposes of the measures. The following summarizes the highway operations-related and performance-related measures:

- Percent of state highway system mainline pavement mileage rated good or very good based on pavement management information system condition score,

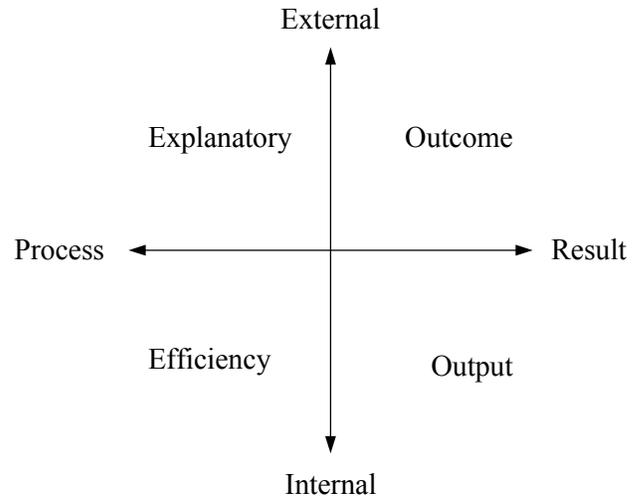


FIGURE 9 Texas DOT's balanced scorecard approach.

- Percent of contracted federal dollars planned with MPOs,
- Total number of centerline-miles that are operational under traffic management systems,
- Percent of on-system bridges structurally deficient or functionally obsolete,
- Percent of highway construction projects with rights-of-way purchased on time,
- Percent of airports needing funding,
- Percent change in the number of public transportation trips,
- Percent of urbanized population living within one-quarter mile of a fixed-transit service route,
- Percent of U.S. Army Corps of Engineers-requested dredge disposal acreage provided,
- Percent of motor vehicle consumer complaints resolved,
- Number of research program products implemented within 2 years,

TABLE 17  
VIRGINIA DOT'S SYSTEM MAINTENANCE AND OPERATIONS PERFORMANCE MEASURES

Performance Measure	Criterion	Data Custodian
Crash rate Equipment crash rate Personal injuries as factor of hours worked and type of site	Safety	Traffic engineering Employee safety and benefits Employee safety and benefits
Traffic movement (number of people moved per hour by corridor)	System operation	Traffic engineering Transportation planning
Sufficiency rating Pavement Structures	Infrastructure quality	Maintenance Structures and bridges

- Percent of engineering-related services contracted with the private sector,
- Statewide traffic crash fatality rate,
- Percent of drivers and front seat passengers complying with safety belt law,
- Percent of car seat/safety belt use for children ages 0–4 years,
- Proportion of driving while intoxicated-related fatal crashes to total fatal crashes,
- Number of high-crash locations improved,
- Percent of advertising signs in compliance with federal law,
- Auto theft rate,
- Economic loss associated with auto theft rate, and
- Road congestion index.

#### Virginia Department of Transportation

The Virginia DOT is moving toward becoming a proactive, customer-focused organization and has implemented a performance-based planning approach to assess agency performance and track the performance of the highway system. This system places a high regard for users' perspectives and this is reflected in their performance measures. The measures identified are derived from goals and objectives. In addition to the system maintenance and operations measures summarized in Table 17, a customer satisfaction goal is also defined.

#### Washington State Department of Transportation

Visual depictions of data can assist users in understanding trends and the meaning of complex data interactions. Visualization techniques available with common simulation software are also useful for demonstrating and educating decision makers about the meaning of various performance measures. ATIS use visualization through websites and interactive maps to assist users in understanding travel conditions using performance measures such as speed, delay, and incidents.

The Washington State Transportation Center (TRAC) at the University of Washington uses innovative techniques to

display their performance measures. Figures 10–12 are examples of the use of innovative displays of performance measures information. Figure 10 is an example of an average daily site profile, composed of three site-specific traffic profiles used by the Washington DOT. The first is a line graph of an average 24-h profile of volume per lane per hour at a selected location for a specified direction of travel (across all lanes), at 5-min increments. The line graph is supplemented by a corresponding 24-h estimated speed profile to show average speeds at each data point on the volume curve. Finally, a 24-h reliability histogram indicates the percentage of time the location is congested, as a function of time of day.

The TRAC program can also produce an average daily corridor profile to depict lane-occupancy percentage at each location along a corridor for a specified direction of travel, at 5-min increments. As seen in Figure 11, the resulting graph is a contour map of the lane-occupancy percentage data (color-coded) according to the estimated congestion level.

The TRAC program can also provide an average travel time profile (Figure 12), which is composed of three 24-h profiles related to a specific trip. The first is a line graph depicting average travel time from one point to another on one corridor as a function of the time the trip starts. A second line graph depicts the 90th percentile travel time as a function of trip start time. Finally, a histogram of trip travel time reliability as a function of trip start time is provided by computing the likelihood (as a percentage) that the overall trip speed is less than 45 miles per hour (mph).

#### MetroPlan Orlando

*Transportation System Indicators Report: Tracking the Trends: 1994–1998*, examines transportation performance trends in the Orlando, Florida, metropolitan area over a 5-year period. The analysis considers several modes of travel, including private automobile, trucking, transit, aviation, rail, bicycling, and walking. The highway performance measures employed include

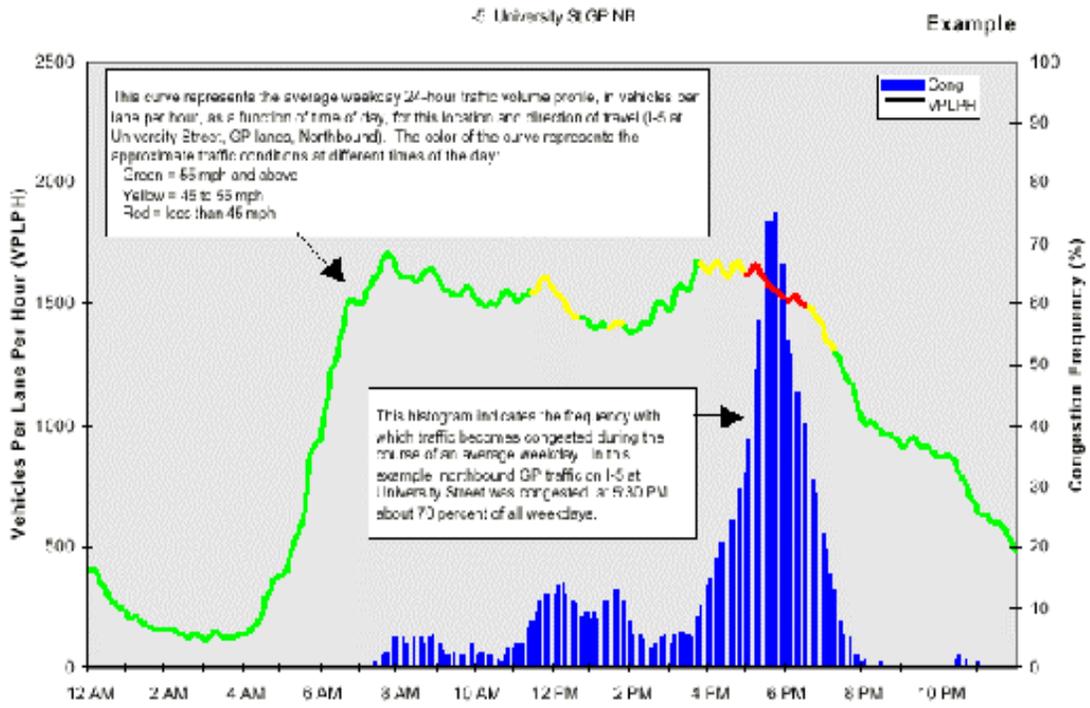


FIGURE 10 Estimated weekday volume, speed, and reliability profiles; I-5 University Street, general purpose, northbound.

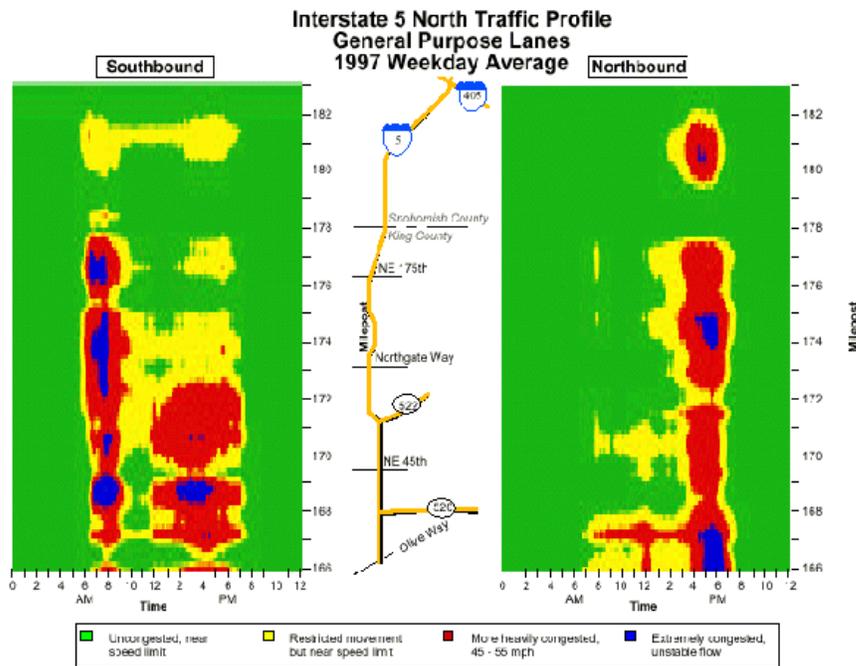


FIGURE 11 Sample temperature diagram of traffic conditions.

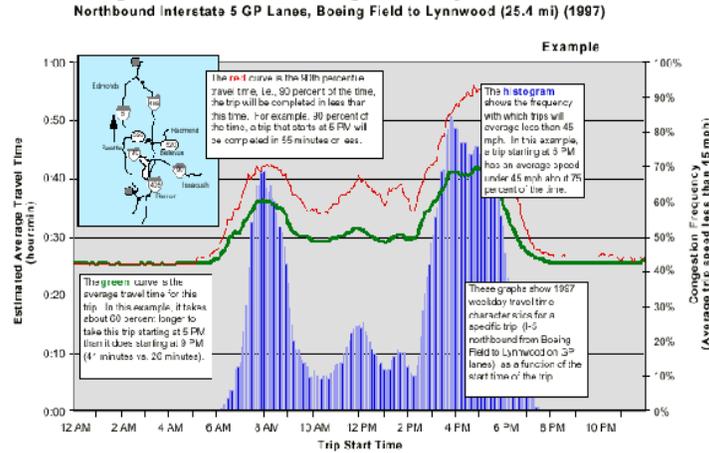


FIGURE 12 Example of estimated average weekday travel time. Northbound I-5, general purpose lanes, Boeing Field to Lynnwood (25.4 mi).

- Traffic congestion index,
- Traffic accident rate, and
- Tons of cargo carried by mode.

number of other interesting performance measures were reported using tables and thematic maps. Trends were also available based on a similar study that was conducted in 1989. The performance measures reported included

**TransGuide DataLink ITS Data Management System**

The DataLink ITS Data Management System was developed by TransLink researchers as a means to easily access and analyze data collected by the TransGuide Transportation Management Center in San Antonio, Texas. The DataLink system contains volume, speeds, and lane-occupancy data collected from loop detectors typically spaced every 0.5 mi aggregated to 5-min intervals. The system is updated daily and archives are available from November 1997 to the present. The performance measures that are used by the system include

- Average speed by lane,
- Average vehicle occupancy by lane,
- Volume by lane,
- Estimated person throughput (volume) by lane,
- Persons times volume times speed by lane, and
- Flow rate (vehicles per hour).

Figures 13–15 provide examples of the graphical user interface capabilities of the system.

**Maricopa County, Arizona, Highway Performance Report**

This report documents the traffic conditions and other key indicators for the Phoenix, Arizona, metropolitan area. These measures were collected using a combination of aerial photo-survey and vehicle detection. The basic purpose of the study was to arrive at LOS for the major facility segments and intersections within the area. However, a

- Weekday traffic volumes,
- Hourly variations in traffic volumes,
- Intersection LOS,
- Duration of intersection LOS F,
- Freeway LOS in general-use lanes,
- Freeway LOS in HOV lanes,
- Duration of LOS F on freeways,
- Employment density by traffic analysis zone,
- Residential household density by traffic analysis zone, and
- Comparison of 1989 and 1998 measures.

**Albany, New York, Metropolitan Planning Organization**

The Albany metropolitan area has been one of the leading users of performance measures in transportation planning in the United States. Beginning in 1992, when the Transportation Improvement Program update process was being revised in light of ISTEA, new approaches were adopted for incorporating system performance into planning and decision making. These measures include

- Access
  - Percentage of person-trips within a defined non-auto to auto difference,
  - Percentage of person-trips with a travel time advantage for non-drive-alone modes, and
  - Number or percent of major freight movements with modal alternatives.
- Accessibility
  - Travel time between representative locations, and

Roadway = 35N bound, Lane, 1998/03/06 MORNING Time (07:00--08:00)

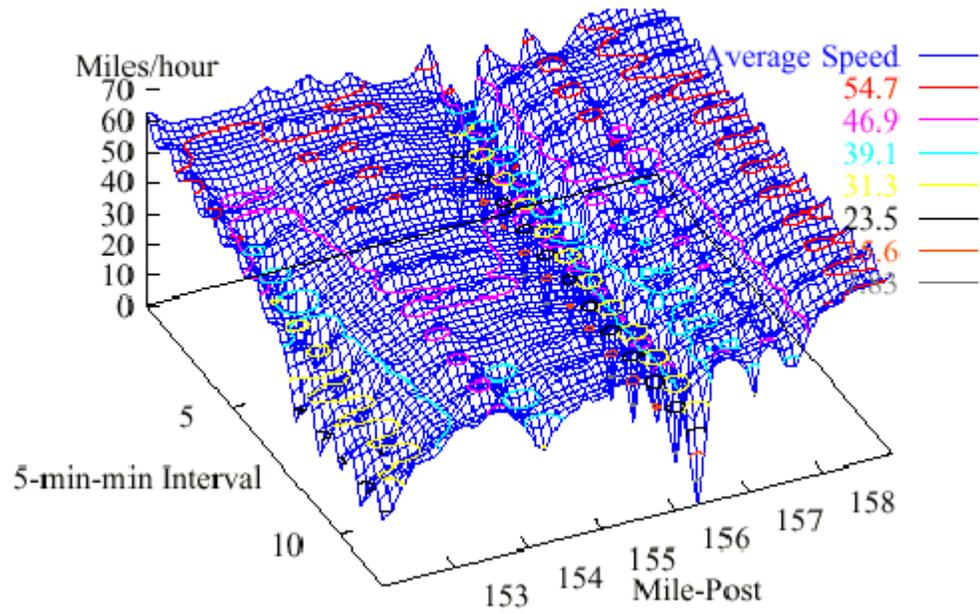


FIGURE 13 Sample display of speed performance measures from TransLink.

Roadway = 35N bound, Lane, 1998/03/06 MORNING Time (07:00--08:00)

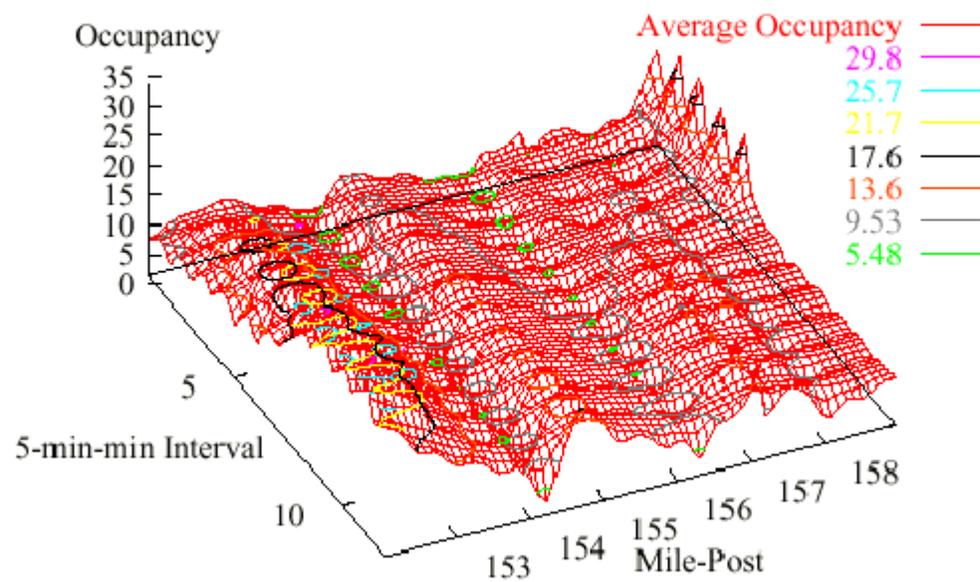


FIGURE 14 Sample display of occupancy performance measures from TransLink.

Roadway = 35N bound, Lane, 1998/03/06 MORNING Time (07:00--08:00)

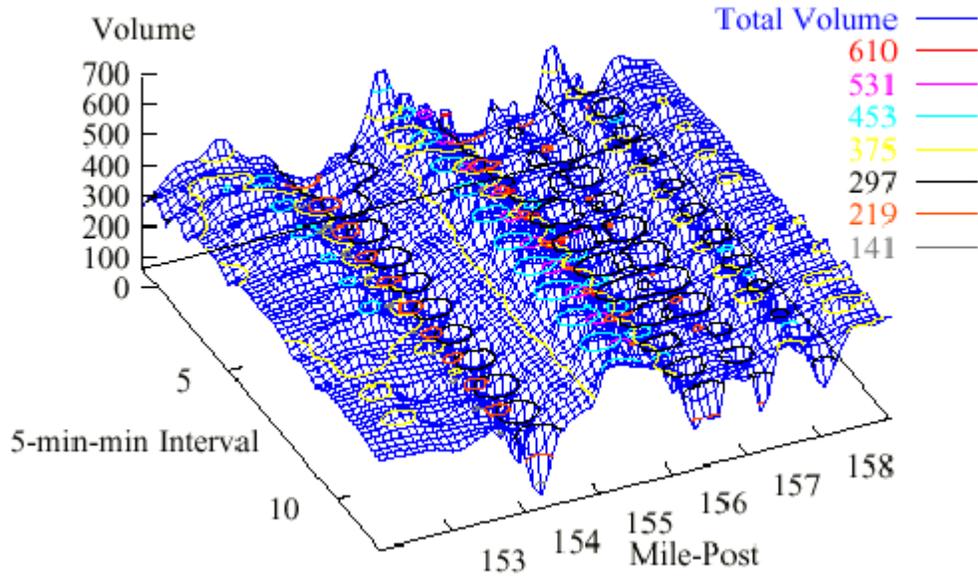


FIGURE 15 Sample display of volume performance measures from TransLink.

- Peak versus nonpeak by quickest mode.
- Congestion
  - Hours of excess delay, recurring and nonrecurring by mode.
- Flexibility
  - Reserve capacity on system,
  - Percentage of person-trips that could be accommodated by modes other than auto, and
  - Number of corridors with reasonable alternatives during closure.
- Safety
  - Estimated societal cost of transport and accidents.
- Energy
  - Equivalent british thermal units/day for transportation capital, maintenance, operation, and use.
- Economic cost
  - Annualized capital, maintenance, operating, and user costs; and
  - Value of commercial time in travel.
- Air quality
  - Daily emission levels, and
  - Air quality attainment status.
- Land use
  - Amount of open space,
  - Dislocation of existing residences and businesses,
  - Land-use transportation compatibility index, and
  - Community character index.
- Environmental
  - Impacts on sensitive areas, and
  - Noise exposure index.

- Economic
  - Narrative discussion of economic activity supporting or constraining features of the transportation system.

**Transportation Research Board Peer Review**

In August 2000, representatives from several states met in Madison Wisconsin, as part of a TRB Peer Review to discuss a range of topics including the quality and consistency of performance measures, data sources, availability and quality, and their use in transportation planning and operations. The states represented included California, Colorado, Florida, Illinois, Kentucky, Maryland, Minnesota, New York, Pennsylvania, and Texas. The Bureau of Transportation Statistics, FHWA, and TRB were also represented.

There was a consensus among the attendees on the challenges of performance measures programs presented during the exchange. These challenges were placed in nine categories as outlined here.

- Market research
  - What existing surveys are available to extract highway performance measures?
  - What lessons have been learned in other similar studies?
  - How can surveys be designed for internal (employees) and external customers?
  - When is market research the right tool?

- How do you develop customer satisfaction indicators?
- How do we develop standard indicators, methods, approaches, and questions?
- Mobility
  - How can we standardize approaches nationally to support a hierarchy of measures?
- Freight mobility
  - What measures are needed to describe freight mobility?
  - What data are needed to support measures?
  - What market segmentations are needed for freight mobility?
  - What intermodal connectivity connections are needed?
- ITS
  - What types of planning and performance measure data are needed from ITS?
  - How can we integrate traditional data collection systems (such as HPMS) with ITS data collection systems?
  - What is the reliability of ITS data compared with traditional statewide monitoring systems?
- Used in state governments
  - What measures are being used in state governments?
  - How do they impact decision making?
  - What is the payoff for policy-level measurement versus engineering-related measurement?
- Safety measures
  - What measures are available beyond accident rates and high accident locations?
  - How are these measures used in states?
- Sustainability measures
  - What measures are appropriate?
  - What data are required to support these data?
- How do we consider measures for growth management?
- How do we address economic justice?
- Goals, objectives, and measures
  - How do states' goals, objectives, and measures relate to federal goals and measures?
  - Is it appropriate to align the goals?
  - What common indicators are needed for all states?
  - How do these questions relate to other areas?
- Quality assurance of data
  - How do you approach data fusion from various databases?
  - How can we standardize data collection processes?
  - How can we leverage partnerships with MPOs and local governments to expand data coverage and share costs?
  - How will privatization affect data quality and standards?
  - What quality assurance standards are needed?
  - How should quality be addressed for new measures when it is difficult to determine quality?
  - How should other data collection efforts be coordinated with HPMS requirements?

This peer review demonstrates the varied use of performance measures in highway operations and there are a broad number of issues and challenges agencies still face in practical application of performance measure programs. The outstanding issues addressed in the review are consistent across all agencies surveyed in this synthesis. For these objectives to be resolved national consensus is needed on a set of core measures that will better serve transportation agencies' needs beyond the existing measures used in programs such as the HPMS and the HCM. These core measures should include standards related to data collection and quality, system coverage for reporting, and aggregation of results.

## STRENGTHS AND WEAKNESSES OF PERFORMANCE MEASURES

Table 18 summarizes commonly used evaluation criteria to assess performance measures that were adapted from other studies that assessed the strengths and weaknesses of performance measures as presented in chapter three.

Table 19 summarizes the strengths and weaknesses of the various measures identified in the research and practices for the operational effectiveness of highway segments and systems based on the criteria. This was performed as part of this synthesis and is not applicable to all situations where performance measures are applied, but is intended to document the relative strengths and weaknesses of the measures for the operational effectiveness of highway segments and systems.

The following measures received a minimum score of 15 out of 20 and were consistently reported in the synthesis of practice. The measures were also recommended based on their ability to serve as foundations for other commonly reported measures, such as congestion index.

- Outcomes (Operational) Performance Measures
  - Quantity of travel (users’ perspective)
    - Person-miles traveled,

- Truck-miles traveled,
- VMT,
- Persons moved,
- Trucks moved, and
- Vehicles moved.
  
- Quality of travel (users’ perspective)
  - Average speed weighted by person-miles traveled,
  - Average door-to-door travel time,
  - Travel time predictability,
  - Travel time reliability (percent of trips that arrive in acceptable time),
  - Average delay (total, recurring, and incident-based), and
  - LOS.
  
- Utilization of the system (agency’s perspective)
  - Percent of system heavily congested (LOS E or F),
  - Density (passenger cars per hour per lane),
  - Percentage of travel heavily congested,
  - V/C ratio,
  - Queuing (frequency and length),

TABLE 18  
CRITERIA PERFORMANCE MEASURES

General Criteria	Specific Criteria
Clarity and simplicity	The measure is simple to present, analyze, and interpret The measure is unambiguous The measure's units are well defined and quantifiable The measure has professional credibility Technical and nontechnical audiences understand the measure
Descriptive and predictive ability	The measure describes existing conditions The measure can be used to identify problems The measure can be used to predict change and forecast condition
Analysis capability	The measure reflects changes in traffic flow conditions only The measure can be calculated easily The measure can be calculated with existing field data There are techniques available to estimate the measure The results are easy to analyze
Accuracy and precision	The measure achieves consistent results The accuracy level of the estimation techniques is acceptable The measure is sensitive to significant changes in assumptions The precision of the measure is consistent with planning applications The precision of the measure is consistent with an operation analysis
Flexibility	The measure applies to multiple modes The measure is meaningful at varying scales and settings

Adapted from Meyer (1995), Turner et al. (1996), Lomax et al. (1997), and Jackson et al. (2000).

TABLE 19  
STRENGTHS AND WEAKNESSES OF VARIOUS PERFORMANCE MEASURES

Performance Measure	Overall Score	Clarity and Simplicity (out of 5)	Descriptive and Predictive Capability (out of 5)	Analysis Capability (out of 4)	Accuracy and Precision (out of 4)	Flexibility (out of 2)
Accessibility	8	0	0	3	3	2
Air quality impacts	16	5	3	3	3	2
Bridge condition	16	5	4	4	3	0
Capital costs in proportion to travel time savings	9	3	0	3	3	0
Commercial vehicle safety violations	14	5	2	4	3	0
Congestion cost per capita	13	5	1	3	3	1
Congestion cost per eligible driver	13	5	1	3	3	1
Congestion index	10	2	2	3	3	0
Cost-effectiveness (benefit/cost ratio)	11	3	0	3	3	2
Customer satisfaction—ability to bid projects	13	5	3	2	3	0
Customer satisfaction—ease of driver licensing	13	5	3	2	3	0
Customer satisfaction—ease of payment of taxes and fees	14	5	3	2	3	1
Customer satisfaction—ease through construction zones	13	5	3	2	3	0
Customer satisfaction—satisfaction with HOV lanes	14	5	3	2	3	1
Customer satisfaction—satisfaction with ramp meters	13	5	3	2	3	0
Customer satisfaction—satisfaction with service patrols	13	5	3	2	3	0
Customer satisfaction—satisfaction with traveler information	14	5	3	2	3	1
Customer satisfaction—streamlined procedures for contracting	13	5	3	2	3	0
Delay caused by incidents	17	5	2	4	4	2
Delay per capita	13	5	1	3	3	1
Delay per eligible driver	13	5	1	3	3	1
Delay, recurring	20	5	5	4	4	2
Delay, total	20	5	5	4	4	2
Density (vehicles per hour per lane)	19	5	5	4	4	1
Density (vehicles per lane-mile)	18	5	4	4	4	1
Duration of congestion	19	4	5	4	4	2
Efficacy of freight movements	8	0	2	3	3	0
Equity/environmental justice	6	0	1	2	3	0
Evacuation clearance time	15	5	3	3	3	1
Guardrail blunt ends	12	5	2	3	2	0
Incident response time	17	5	3	4	4	1
Incidents (fatal) per million vehicle-miles	17	5	3	4	4	1
Incidents (injury) per million vehicle-miles	16	5	3	3	4	1
Incidents (number of crashes or stopped vehicles)	17	5	3	4	4	1
Incidents (property damage only) per million vehicle-miles	16	5	3	3	4	1
Lane-use and development permit data	8	1	1	3	3	0
Lane occupancy	14	3	3	4	4	0
Level of service	17	5	4	3	4	1
Noise levels	14	4	3	4	3	0
Number of miles operating in desired speed range	19	5	5	4	4	1
Number of trips made per person	14	5	2	4	3	0
Pavement condition	18	5	4	4	4	1
Percent of ITS equipment operational	17	5	3	4	4	1
Percent of system congested	14	3	3	3	4	1
Percent of travel congested	15	3	3	3	4	2
Person-miles traveled	20	5	5	4	4	2
Population and employment	14	5	3	3	3	0
Project timeliness	13	5	2	3	3	0
Queuing of traffic (frequency)	18	5	5	4	4	0
Queuing of traffic (length)	18	5	5	4	4	0
Rail crossing incidents	17	5	3	4	4	1
Response time to weather-related incidents	15	4	2	4	4	1
Response times to incidents	15	4	2	4	4	1
Seat belt use	12	5	2	2	3	0
Security for highway and transit	13	4	3	3	3	0
Speed	20	5	5	4	4	2
Toll revenue	16	5	3	3	3	2
Traffic volume	19	5	5	4	4	1
Travel costs	14	4	3	3	3	1

TABLE 19 (Continued)

Travel rate index	10	3	1	3	3	0
Travel time	19	5	5	4	4	1
Travel time predictability	18	5	5	3	4	1
Travel time reliability	15	3	3	4	4	1
Vehicle-miles traveled	19	5	5	4	4	1
Vehicle occupancy (persons per vehicle)	18	5	3	4	4	2
Volume/capacity ratio	19	5	5	3	4	2

TABLE 20  
COMMON DATA COLLECTION STANDARDS FOR PERFORMANCE MONITORING AND ADVANCED TRAVELER  
INFORMATION SYSTEMS

Data Element	Attribute	Supplemental Data Elements
Vehicle travel times	5-min average for all roadways with required coverage	<ul style="list-style-type: none"> <li>• Date of measurement</li> <li>• Start time of travel time</li> <li>• Anonymous vehicle identification</li> <li>• Link identification</li> </ul>
Vehicle spot speeds	5-min averages by lane using actual speed observations for all roadways with required coverage	<ul style="list-style-type: none"> <li>• Date of measurement</li> <li>• Start and end time for speed summary statistics</li> <li>• Detector location identification and location</li> </ul>
Vehicle volumes	5-min totals by lane for all roadways with required coverage	<ul style="list-style-type: none"> <li>• Date of measurement</li> <li>• Start and end time for volume summary statistics</li> <li>• Detector location identification and location</li> </ul>
Roadway link and corridor identification	Links of 1–3 mi along arterials and between each interchange along limited-access roadways	<ul style="list-style-type: none"> <li>• Detector location identification and location</li> <li>• Roadway name and direction</li> <li>• Link length</li> <li>• Number of lanes</li> <li>• Posted speed limit</li> <li>• Area type (urban, urbanized transitioning, rural)</li> <li>• Functional classification (freeway, arterial, collector)</li> </ul>
Vehicle classification	Using FHWA’s 13 vehicle classes as defined in the Traffic Monitoring Guide	<ul style="list-style-type: none"> <li>• Date of measurement</li> <li>• Start and end time for volume summary statistics</li> <li>• Detector location identification and location</li> </ul>

- Percent of miles operating in desired speed range,
- Vehicle occupancy (persons per vehicle), and
- Duration of congestion (lane-mile-hours at LOS E or F).
- Safety
  - Incident rate by
    - ☐ Severity (fatal, injury, or property damage), and
    - ☐ Type (stopped vehicles, rail crossing, weather, or crashes).
- Incidents
  - Incident induced delay, and
  - Evacuation clearance time.
- Outputs (agency performance)
  - Incident response time by type
    - Stopped vehicle,
    - Rail crossing,
    - Weather, and
    - Crashes.
  - Toll revenue,
  - Bridge condition,
  - Pavement condition, and
  - Percent of ITS equipment operational.

In addition to identifying these performance measures, some common data collection requirements to support these measures were identified in this synthesis of practice. Table 20 summarizes these data requirements.

## CONCLUSIONS

This synthesis of research examined the use of performance measures for the monitoring and operational management of highway segments and systems. The current state of the practice includes a wide and varied approach to performance measures, and more than 70 performance measures were identified. The relative strengths and weaknesses of the measures were reported based on professionally accepted criteria. The performance measures that were most commonly identified were conditions experienced by the traveler, such as travel time, speed, and delay. Measures that are derived from these basic units, primarily indices, were found to be less relevant to the operational environment, but very valuable for transportation planning, policy, and prioritization analysis. Based on the results of the survey of state departments of transportation and metropolitan planning organizations, the dimensions of operational performance that were the most relevant were the quantity of travel and the quality of travel.

Through this synthesis of research and practice several research needs were identified as important to enhance and expand the state of the practice.

- Because of the diversity in the use and application of performance measures nationally and their formative status (not mature and well tested), several measures such as reliability have been defined differently. A data dictionary of performance measures is needed that defines the use and application of derived measures such as reliability and the indices. Several of the seminal works identified in the literature review are approaching this status of a *de facto* standard; however, more formal policies and guidelines are needed. Inclusion of a broader range of operational performance measures and recommended practices such as the Highway Performance Monitoring System and TRB's *Highway Capacity and Quality of Service Manual* will promote this needed convergence. The FHWA's Intelligent Transportation Infrastructure Program established standards for data collection quality and reporting; however, these standards have not been widely adopted.
- Additional information is needed in the use of performance measures in operational environments. The nation's emerging intelligent transportation systems will provide a strong operational platform for the more formal application, use, and study of the benefits of performance-based management. However, without strong leadership, diverse and more informal practices are likely to continue that make system evaluation, aggregation of statistics, and comparisons of operational scenarios more difficult.
- Information is also needed to develop standards for data quality and coverage to support operational needs, advanced traveler information systems, and systemwide reporting. Several guidelines are currently available, such as *Closing the Data Gap: Guidelines for Quality Advanced Traveler Information System Data* published by ITS America and the Intelligent Transportation Infrastructure Program's data quality standards. These standards could be unified and developed so that deployment of data collection systems can serve multiple purposes and achieve synergistic effects.
- None of the case studies explicitly addresses accuracy or precision in the presentation of their results. This is a major challenge for the advancement of mobility performance measures programs. In addition to the data definition and quality standards identified earlier, recommended practices for reporting of performance measures are needed. These recommended practices could include reporting standard errors or confidence intervals as a common practice.
- Few agencies have addressed the need to forecast performance measures and to address the sensitivity of policy or travel behavior changes. Once national practices are established to consistently report on trends and a sufficient database has been developed over time, the next logical extension will be the forecasting of these trend data and the testing of alternate policies and scenarios. A national practice is needed that will guide policy and system planners in this technique.
- Operational performance measures that address evacuations from man-made or natural disasters are needed. During these conditions of urgency, the efficient use of transportation resources to remove people and resources from harm's way is very important. Several agencies deploy measures such as clearance time (the time it takes for an evacuee to move outside of the danger zone); however, these measures are used primarily in post-event evaluations. Use of performance measures during the operations of these events and tailoring strategies to maximize/optimize performance based on these measures could improve effectiveness.

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## ACRONYMS AND ABBREVIATIONS

ATIS	Advanced Traveler Information System
CHART	Coordinated Highways Advisory Response Team
GPS	global positioning system
HCM	<i>Highway Capacity Manual</i>
HOV	high-occupancy vehicle
HPMS	Highway Performance Monitoring System
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
ITIP	Intelligent Transportation Infrastructure Program
ITS	intelligent transportation system
LOS	level of service
mph	miles per hour
MPO	metropolitan planning organization
NCHRP	National Cooperative Highway Research Program
NHS	National Highway System
NPTS	National Personal Transportation Survey
PL	Planning Funds Program of FHWA
RCI	Roadway Characteristics Inventory
RTMS	Radar Traffic Monitoring System
TCM	transportation control measures
TDM	travel demand management
TIP	Transportation Improvement Program
TMC	traffic management center
TOC	traffic operations center
TQM	Total Quality Management
TSM	Transportation Systems Management
TTI	Texas Transportation Institute
U.S. DOT	U.S. Department of Transportation
V/C	volume/capacity
VMT	vehicle-miles traveled

## APPENDIX A

### Survey Questionnaire

#### NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

##### NCHRP PROJECT 20-5

##### SYNTHESIS OF HIGHWAY PRACTICE 32-07

#### PERFORMANCE MEASURES OF OPERATIONAL EFFECTIVENESS FOR HIGHWAY SEGMENTS AND SYSTEMS

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Twentieth-century surface transportation programs were substantially focused on the development of basic infrastructure networks. The challenge for transportation in the 21st century is managing and operating these transportation resources to deliver needed services to customers under varying conditions in the face of growing travel demand and capacity limitations. Performance measurement is emerging as a critical tool to help meet this challenge. It is being used at several levels, ranging from day-to-day operations to long-term capital planning that enhances system operations. It can also be used at the project level to identify design features that improve operations and at the policy level to allow stakeholders to evaluate the benefits of highway improvements. However, evaluating and improving system operations through performance measures can be challenging. Data collection and analysis demands can be overwhelming. Different measures are appropriate for different audiences, e.g., the public, elected officials, system planners, and operations managers. Engineering measures may be useful in improving operations, but may not be effective in communicating meaningful information to the public.

This synthesis will summarize the practices concerning highway operational performance measures and associated data collection (e.g., link travel times, duration of congestion, reliability, LOS, seasonal road closures, recurring and non-recurring delays). How they are collected and put to use, their relative strengths, weaknesses, and the usefulness of these measures for various audiences and purposes will be documented. Successful practices will also be highlighted using agency profiles. The following survey is designed to support this analysis.

This survey should be completed by those in your agency who are familiar with your agency's activities related to operations and performance measures. Your responses are important regardless of the current use of performance measure in your agency.

**Please respond to the survey by September 1, 2001 or provide any comments or questions to:**

**Terrel Shaw, PE  
Principal Investigator  
PBS&J  
1901 Commonwealth Lane  
Tallahassee, Florida 32303  
(850) 576-2788  
(850) 575-1513 fax  
terryshaw@pbsj.com**

**Survey on the Use of Performance Measures for the Operational Effectiveness  
of Highway Systems and Segments**

**Background Information**

- 1. Name: \_\_\_\_\_
- 2. Title: \_\_\_\_\_
- 3. Agency: \_\_\_\_\_
- 4. Address: \_\_\_\_\_
- 5. City/State/Zip: \_\_\_\_\_
- 6. Phone: \_\_\_\_\_ 7. Fax: \_\_\_\_\_
- 8. E-mail: \_\_\_\_\_ 9. Website: \_\_\_\_\_
- 10. May we contact you for additional information? Yes  No
- 11. Would you like your responses to be confidential? Yes  No
- 12. What part of the agency do you work in? Planning  Design  Other  \_\_\_\_\_

**Agency Profile Information**

- 13. Is your agency a: State Department of Transportation  Headquarters  or Region   
 Metropolitan Planning Organization   
 City or County   
 Other type of agency  \_\_\_\_\_
- 14. What is the population of the area for which your agency has jurisdiction?  
 5 million or more   
 1 million to 4,999,999   
 500,000 to 999,999   
 Less than 500,000
- 15. How many centerline-miles of roadways are present in your agency’s jurisdiction? \_\_\_\_\_
- 16. Is your agency responsible for the operation of streets, highways, or toll roads? Yes  No
- 17. Is your agency responsible for traffic data collection systems? Yes  No
- 18. Is your agency responsible for the operation of intelligent transportation systems (ITS)? Yes  No
- 19. Is your agency involved in project planning and decision making? Yes  No
- 20. Does your agency currently use performance measures in the operational analysis of highways?  
 No   
 Yes

21. If yes, what performance measures are used?

- Traffic volume
- Vehicle-miles traveled
- Travel time
- Speed
- Density (passenger cars per hour per lane)
- Recurring delay
- Level of service/Highway Capacity Manual
- Duration of congestion
- Travel time reliability
- Percent of travel congested
- Percent of system congested
- Travel costs
- Vehicle occupancy
- Number of incidents
- Weather-related traffic incidents
- Rail grade crossing incidents
- Duration of delay caused by incidents
- Response times to incidents
- Commercial vehicle safety violations
- Security for highway and transit
- Weather-related road closures
- Response time to weather-related closures
- Evacuation times
- Toll revenue
- Delay from toll collection
- Delay from incidents

22. Any others? Please specify.

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23. What measures are most important and why?

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24. Why do you consider performance measures (check all that apply)?

- Quality Initiative
- Legislative Mandate
- Planning Process
- ITS Operations
- ITS Evaluation
- Other \_\_\_\_\_

25. How long have you used performance measures? \_\_\_\_\_ years

26. Who is your audience for performance measures (elected officials, agency management, public, etc.)?

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27. If a summary of the performance measures employed by your agency is available, please provide a copy or a link to a website with your response to the survey.

Website location: \_\_\_\_\_

28. What was the process used to define which measures will be used?

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29. How are the measures reported?

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30. Who is the audience for the performance measures reporting?

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31. What media are used in reporting the measures?

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32. What format is used in reporting the measures?

- Tables  Graphs/Charts  Maps  Text  Other \_\_\_\_\_

33. How are the measures used in operations?

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34. Are there any other uses than operations of performance measures by your agency?

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35. What is your agency's role in defining and collecting data to support these measures?

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36. What data are collected to support the performance measures?

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37. What technologies are used to collect the data?

<u>Technology</u>	<u>Which measures?</u>
Inductive loops?	_____
Video detection?	_____
Probe vehicles or travel time studies?	_____
Road tubes?	_____
Radar/acoustic?	_____
Customer survey?	_____
Modeling/estimation?	_____
Others? _____	_____

38. What technologies are used to collect the data (inductive loops, ViDS, RTMS, etc.)

\_\_\_\_\_  
\_\_\_\_\_

39. What percentage of the system is covered? \_\_\_\_\_%

40. How was this coverage selected?

\_\_\_\_\_  
\_\_\_\_\_

41. How frequently are the data collected?

\_\_\_\_\_  
\_\_\_\_\_

42. What are the approximate costs of the data collection (if costs are not available, how many people in full-time equivalents are involved)?

\_\_\_\_\_  
\_\_\_\_\_

43. Is some of your data provided by another agency? If so, please explain.

\_\_\_\_\_  
\_\_\_\_\_

44. Are these costs in addition to other data collection programs or are they part of another data collection requirement/system such as HPMS?

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

45. How are the data collection funded?

\_\_\_\_\_  
\_\_\_\_\_

46. How is the data stored and who is responsible for the data?

\_\_\_\_\_  
\_\_\_\_\_

47. How long are the data stored?

\_\_\_\_\_  
\_\_\_\_\_

48. Who are the users of the stored data?

\_\_\_\_\_  
\_\_\_\_\_

49. Which measures, if any, are used only in “real-time”?

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50. Who are the users of the “real-time” data?

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51. Would you like to receive a copy of this synthesis when complete?      Yes  No

**Thank you for your participation!**

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